NOLAN CREEK

Characterizing Potential Pollutant Loads to Nolan Creek/South Nolan Creek

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For more information about this document or any other document TIAER produces, send email to info@tiaer.tarleton.edu. More information about the Nolan Creek/South Nolan Creek project can be accessed from the project website at: http://www.killeentexas.gov/nolancreekwatershed.

Cover photograph is Nolan Creek at Backstrom Crossing (station 11905) taken on May 21, 2015.

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SECTION 1

Introduction

Nolan Creek/South Nolan Creek Watershed

Nolan Creek/South Nolan Creek (Segment 1218) flows into the Leon River within the Brazos River Basin southeast of Belton, Texas (Figure 1-1). Segment 1218, as defined by the Texas Commission on Environmental Quality (TCEQ), stretches nearly 30 river miles from its confluence with the Leon River in Bell County to a point 100 meters upstream to the most upstream crossing of US 190 and Loop 172 in Bell County. The Nolan Creek/South Nolan Creek watershed comprises about 72,800 acres, large portions of which are urban (about 40 percent developed, see Figure 1-2 and Table 1-1). The creek flows through the cities of Killeen, Harker Heights, Nolanville, and Belton, and the watershed area also includes portions of the Fort Hood Military Reservation.

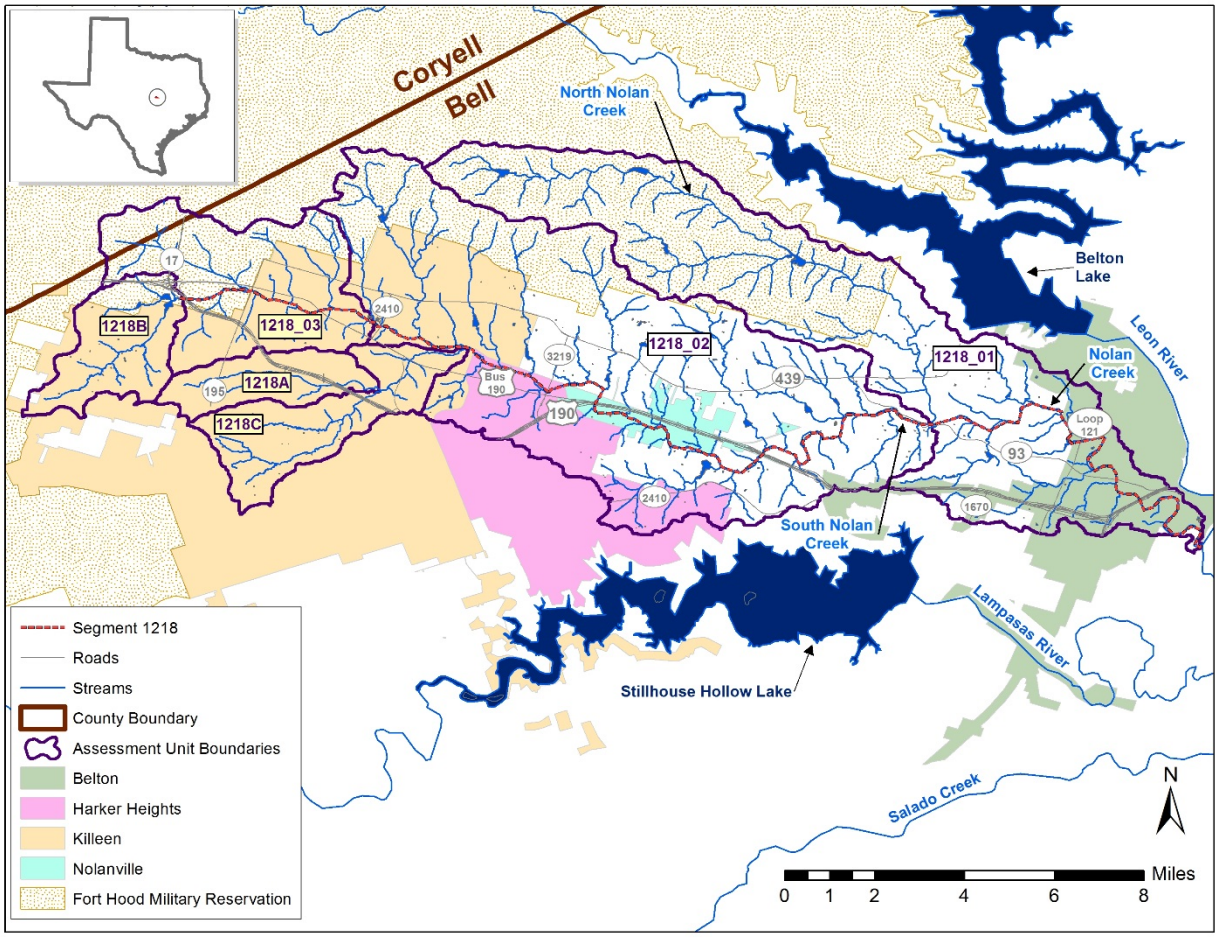

Figure 1-1 Watershed and assessment units associated with Segment 1218, Nolan Creek/South Nolan Creek. Inset shows watershed location within the State of Texas.

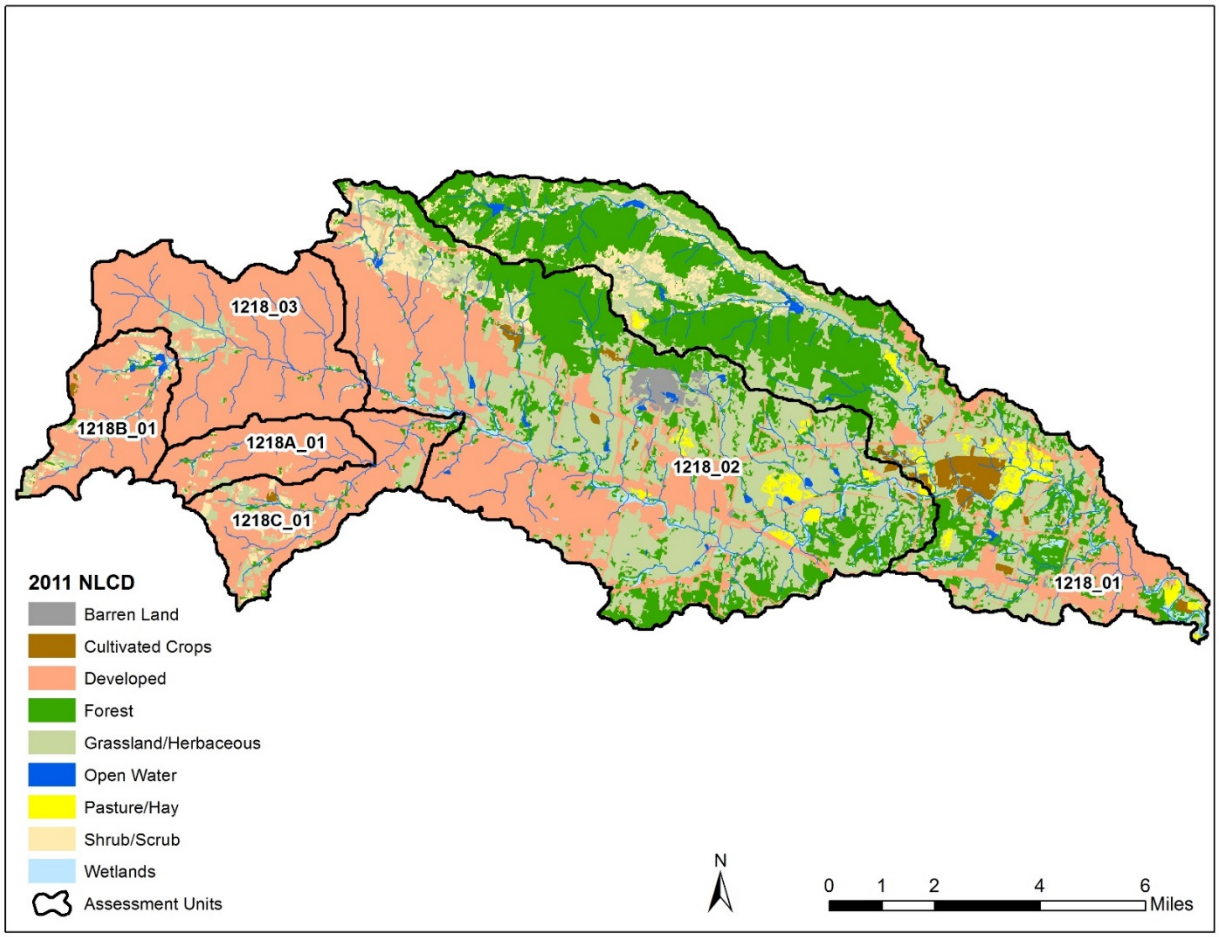

Figure 1-2 Land use/land cover for the Nolan Creek/South Nolan Creek watershed. Source: 2011 National Land Cover Database (USGS, 2014a).

Assessment of water quality along Nolan Creek/South Nolan Creek indicates that Segment 1218 is impaired with regard to bacteria and the use of primary contact recreation (TCEQ, 2013). The bacteria impairment is specifically noted for assessment units 1218_02 and 1218C (Figure 1-1). Segment 1218_02 was first listed as impaired for bacteria in 1996, while water body 1218C was not listed until 2010. The draft 2014 Texas Water Quality Inventory continues to list these same impairments (TCEQ, 2014). As a result of these impairments, the Texas Institute for Applied Environmental Research (TIAER) is working with stakeholders through the Nolan Creek Partnership to characterize bacteria sources and loadings within the watershed. This information will then be used to help define management practices for the reduction of loadings.

Table 1-1 Comparison of land use/land cover for the Nolan Creek/South Nolan Creek watershed with Bell County. Source: 2011 National Land Cover Database (USGS, 2014a).

Category	Nolan Creek/South Nolan Creek Watershed (%)	Nolan Creek/South Nolan Creek Watershed (acres)	Bell County (%)	Bell County (acres)
Developed	40.1	29,196	13.3	92,480
Barren	0.8	590	0.3	2,086
Forest	22.6	16,708	17.5	121,684
Shrub/Scrub	4.2	3,040	4.3	29,899
Grassland Herbaceous	26.8	19,517	32.0	222,508
Pasture Hay	1.5	1,072	7.5	52,150
Cultivated Crops	1.4	991	19.0	132,114
Wetlands	1.8	1,337	2.9	20,165
Open Water	0.5	360	3.2	22,251
Totals	100.0	72,811	100.0	695,336

The purpose of this report is to present an overview of potential bacterial loadings within the Nolan Creek/South Nolan Creek watershed using Load Duration Curves (LDCs) and the Spatially Explicit Load Enrichment Calculation Tool (SELECT). As nutrients are also a concern in the watershed (TCEQ, 2013), LDCs were also developed for relevant nutrient parameters of nitrate, orthophosphate-phosphorus (ortho-P), and total-phosphorus (total-P).

Load Duration Curves

The LDC approach was developed to aid in assessing nutrient loadings in streams (EPA, 2007) and is now commonly used in evaluating bacteria loadings (e.g., Johnson et al., 2009). Several publications promote the use of a LDC approach in evaluating water quality problems, particularly in watersheds with limited stream data, and provide detailed guidance on LDC development and interpretation (e.g., Morrison and Bonta, 2008; EPA, 2007; Bonta and Cleland, 2003; Cleland, 2002; 2003; Bonta, 2002). The LDC methodology is simple to apply and effective in differentiating point and nonpoint contributions based on flow regime (EPA, 2007; Cleland, 2003). The flow regime is defined using a duration curve, which is a graph that illustrates the percentage of time a given flow is equaled or exceeded based on long-term stream data. The FDC, thus, identifies general hydrologic conditions (i.e., wet versus dry) and generally how long each condition occurs (Cleland, 2003). For example in Figure 1-3, average daily flows

exceed 54 cfs 30 percent of the time and 30 cfs 50 percent of the time. Average daily flow exceed 9 cfs 100 percent of the time.

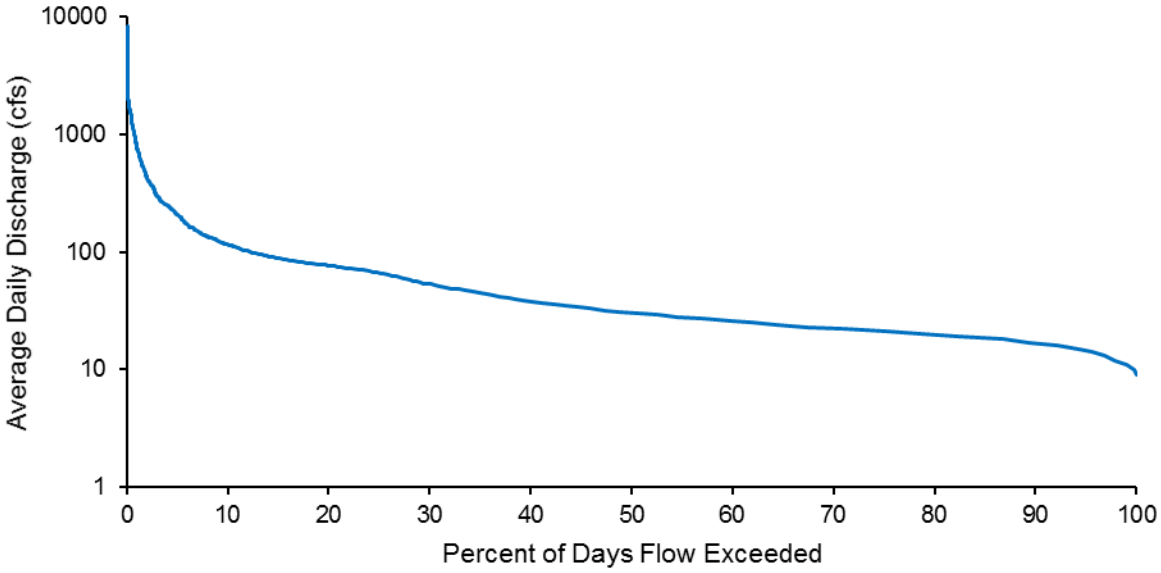

Figure 1-3 Flow duration curve based on daily data from January 31, 1974 through November 3, 1982 for station 08102600 on Nolan Creek at Belton, Texas. Source: USGS (2014b).

A LDC, which is related to the FDC, shows the corresponding relationship between contaminant loadings and stream flows for a given station and is developed by associating a concentration, generally the water quality criterion or screening level, with each flow value to develop a series of allowable loadings. Monitoring data representing the concentration of the constituent of interest collected at a given flow is then overlaid with the allowable LDC to aid in identifying flow conditions under which allowable or desired loads are exceeded. By relating loads to flow conditions, LDCs assist in determining patterns in pollution loadings with varying streamflow. If exceedances occur primarily during low flow conditions, then point sources are likely the contributing source, while if exceedances occur primarily during high flow conditions, then nonpoint sources are likely the contributing source. Load duration curves are also important as they can be used to estimate load reductions that will be needed from management measure to meet water quality goals.

Spatially Explicit Load Enrichment Calculation Tool

While LDCs are useful in narrowing down the causes of potential pollutants as either point or nonpoint sources, other tools can help differentiate potential sources within these two broad categories. Researchers with the Department of Biological and Agricultural Engineering and the Spatial Science Laboratory at Texas A&M University developed SELECT as a screening tool for evaluating potential bacteria loads resulting from various sources within a watershed (Teague, et al., 2009). This tool is based on the Bacteria Source Load Calculator (BSLC) developed at the Center for TMDL and Watershed Studies at Virginia Tech (Zeckoski, et al., 2005), but builds on the BSLC approach by providing a spatial display of potential loadings. Within a watershed,

SELECT calculates potential bacteria loadings from various sources and then allocates these potential loadings via an ArcGIS environment at a sub-watershed level. Delineating the watershed into smaller sub-watersheds aids in targeting specific areas that may be “hot spots” for potential bacteria loadings. Potential loads are based on land-use classification with regard to the distribution of nonpoint sources, such as grazing livestock and wildlife, and state and municipal sources for most point sources, such as wastewater treatment facilities (WWTFs).

Of note, loadings estimated via SELECT f do not take into account losses associated with treatment or transport across the landscape or in-stream (Teague et al., 2009). These potential loadings present what might be considered a “worst case” scenario assuming all fecal material produced by a given source were to make it into the stream system. With natural transport processes, there are some losses of bacteria loadings from the landscape to the stream system, as well as die-off and regrowth that can occur over time. The details associated with the fate and transport processes of bacteria are quite complex (e.g., Benham et al., 2006 and Vidon et al., 2008) and are outside the scope and purpose of SELECT. The purpose of SELECT is to highlight potential sources and contributing areas within a watershed where it may be prudent to apply more focused educational efforts on implementing bacteria control practices and not to calculate specific loadings.

SECTION 2

Estimated Pollutant Loads and Load Reductions

Flow Duration Curves

For the Nolan Creek/South Nolan Creek watershed, LDCs were developed for four location at which direct monitoring data were collected (Figure 2-1). These were stations

- 18828 located on South Nolan Creek at 38th Street in Killeen,
- 11913 located on South Nolan Creek at Roy Reynolds Road in Killeen,
- 11910 located on South Nolan Creek at US Highway 190 in Nolanville, and
- 11905 located on South Nolan Creek at Backstrom Crossing.

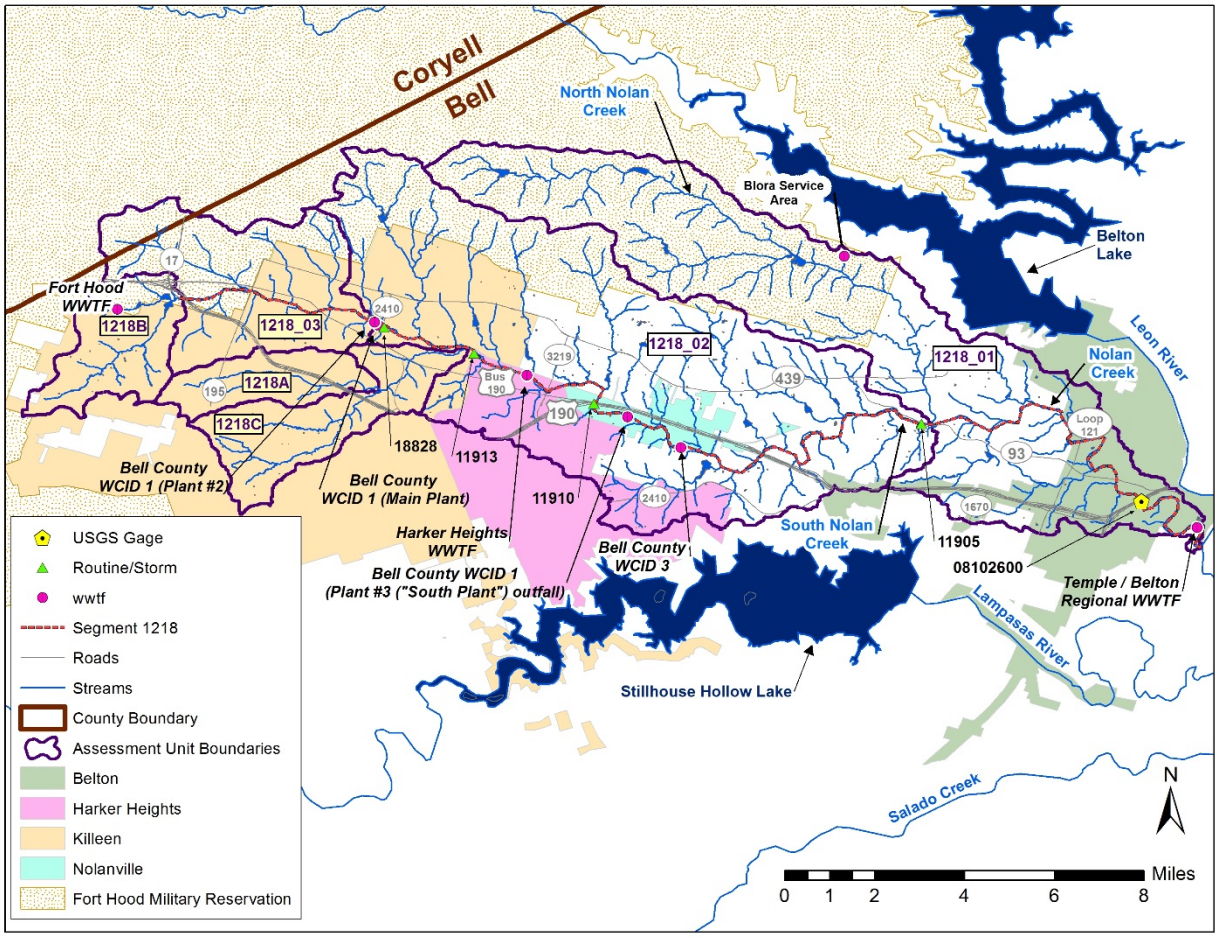

Figure 2-1 Monitoring stations and wastewater treatment facility (WWTF) discharge locations used in FDCs and LDCs along Nolan Creek/South Nolan Creek.

Because streamflow data for these four stations were very limited (less than 2 yrs), FDCs were estimated based on historical flows monitored at USGS station 08102600 on Nolan Creek at Belton as the best available long-term data (see Figure 1-3; USGS, 2014a). To develop the FDCs for the four monitoring locations, drainage area ratios were developed between each monitoring station and the USGS station on Nolan Creek (Table 2-1). Because at low flows, wastewater treatment facility (WWTF) discharges can be prominent contributor to flow, estimates of the average daily discharge from each WWTF was obtained from the EPA Enforcement and Compliance History Online (ECHO) website for each facility that discharged above station 08102600 (Table 2-2). Of note, the Temple Belton Regional WWTF discharges below the location of station 0818266, and, thus, is not included in Table 2-2. The FDC for station 08102600 shown in Figure 1-3 was generated by

1) Ranking daily flows from highest to lowest
2) Calculating the percent of days each flow value was exceeded (rank/(number of data points)*100
3) Plotting each flow value (y-axis) against it exceedance value (x-axis).

The FDCs for each monitoring station were then estimated from the FDC for station 08102600 by first adjusting the streamflow record by removing the estimated WWTF discharges. Estimated WWTF discharges were based on the mean of reported values (Table 2-2). This adjusted streamflow was then multiplied by the drainage area ratio (DAR) for each monitoring station and then the estimated WWTF discharge above each monitoring station was added to the DAR-adjusted flow (Figure 2-2).

Table 2-1 Area and drainage area ratios for monitoring stations compared to USGS station 08102600 on Nolan Creek.

Station	Area (acres)	Drainage Area Ratio
18828	12,388	0.173
11931	24,089	0.336
11910	34,072	0.475
11905	49,415	0.689
USGS 08102600	71,680	1.000

It is recognized that the time period for the USGS data at station 08102600 differs from the time period of readily available WWTF data. For FDCs, it is assumed that the data used represents an average of long-term conditions and not specific dates. To evaluate potential climatic influences, a check was done comparing FDC estimates for the station 08103800 on the Lampasas River at Kempner using data from 1974 through 1982 compared to 2005 through 2014. The Lampasas River at Kempner was selected as it is in the same region as the Nolan Creek USGS station and had the best correlation with daily flows for Nolan Creek. While not exactly the same, the two curves generated were similar indicating that the discharge history from station 08102600 on Nolan Creek from 1974 through 1982 should be fairly representative of longer-term conditions.

Table 2-2 Estimated average daily discharge from WWTFs above station 08102600 on Nolan Creek/South Nolan Creek. Source: EPA ECHO.

EPA ID	Facility Name	Mean (MGD)	Median (MDG)	Standard Deviation (MGD)	Min. (MDG)	Max. (MGD)	First Record	Last Record	Number of Obs.
TX0101869	Universal Services Ft Hood WWTF	0.05	0.05	0.01	0.04	0.06	Aug-10	May-15	58
TX0024597	Bell County WCID No. 1 WWTF (Main Plant)	11.2	10.8	1.82	8.77	18.7	Aug-10	Jun-15	59
TX0102938	Bell County WCID No. 1 (Plant 2)	0	0	0	0	0	Aug-10	Mar-13	0
TX0024473	City of Harker Heights WWTF	1.86	1.83	0.29	1.53	3.25	Aug-10	Jun-15	59
TX0125377	Bell County WCID No. 1 (Plant 3, South Plant)	2.55	2.81	0.88	0.81	4.49	Aug-10	Jun-15	59
TX0069191	Bell County WCID No. 3 WWTF	0.31	0.24	0.42	0.15	2.86	Apr-12	Jun-15	39
TX0132446	Blora WWTF	0.01	0.01	0.01	0.00	0.03	Jul-11	Jun-15	48

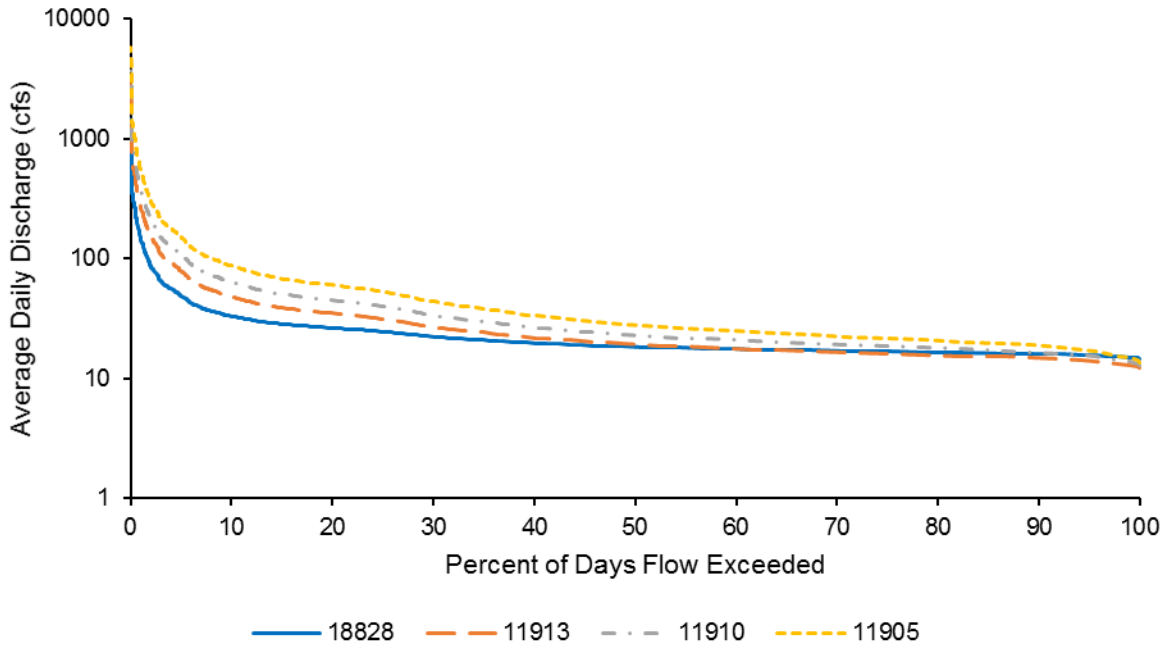

Figure 2-2 Estimated FDCs for stations along Nolan Creek\South Nolan Creek.

Load Duration Curves

To convert FDCs into LDCs, flow data are multiplied by a threshold concentration, which is generally the target level associated with the parameter of interest. For nutrients, screening levels are used for assessment purposes and were considered the target level. Screening levels are 1.95 mg/L for nitrate, 0.37 mg/L for ortho-P, and 0.69 mg/L for total-P (TCEQ, 2012). For bacteria in freshwater systems, *Escherichia coli* is used as the indicator bacteria. Units for *E. coli* are generally given as most probably number per 100 milliliters (MPN/100 mL) or as colony forming units per 100 mL (cfu/100 mL) and used interchangeably. The geometric mean criterion for *E. coli* of 126 MPN/100 mL from the Texas State Water Quality Standards (TSWQS) was used as the target level for LDCs.

Measured data were then superimposed on the graph showing allowable loads by obtaining the load for each sample based on its concentration and flow and relating the measured flow with the corresponding percent exceedance from the FDC. Values below the allowable loading line are considered “in compliance” while values above the allowable loading line are considered “out of compliance.” To further inform, measured data were categorized as influenced by wet or dry weather conditions based on the parameter days since last significant precipitation (DSLP, parameter code 72053). If DSLP was recorded as less than 4 days, the sample was considered to be wet-weather influenced.

The LDCs for bacteria are shown below (Figures 2-3 – 2-6). Because the bulk of this report is focused on bacteria as the waterbody impairment, the LDCs for nutrients are presented in

Appendix A. For all LDCs, the curve was divided into three flow-regimes representing high flows (0-10% exceedance), moderate flows (10-60% exceedance), and low flows (60-100% exceedance). This break in flow regimes generally follows a commonly used set provided by Clevland (2003), although Clevland (2003) further divides moderate flows into moist conditions (10-40% exceedance), mid-range flows (40-60% exceedance), and dry conditions (60-90% exceedance). The available data for Nolan Creek/South Nolan Creek did not appear to warrant this further refinement of flow regimes, so only three flow regimes are presented. In general, the high flow regime (0-10% exceedance) is related to flood conditions and nonpoint source loadings, the moderate flow regime (10-60% exceedance) is related to point and nonpoint source loadings, and the low flow regime (60-100% exceedance) is related to dry conditions and point source loadings. For reference, the geometric mean of measured values within each flow regime is shown at the midpoint of the percent days exceeded (Figures 2-3 – 2-6).

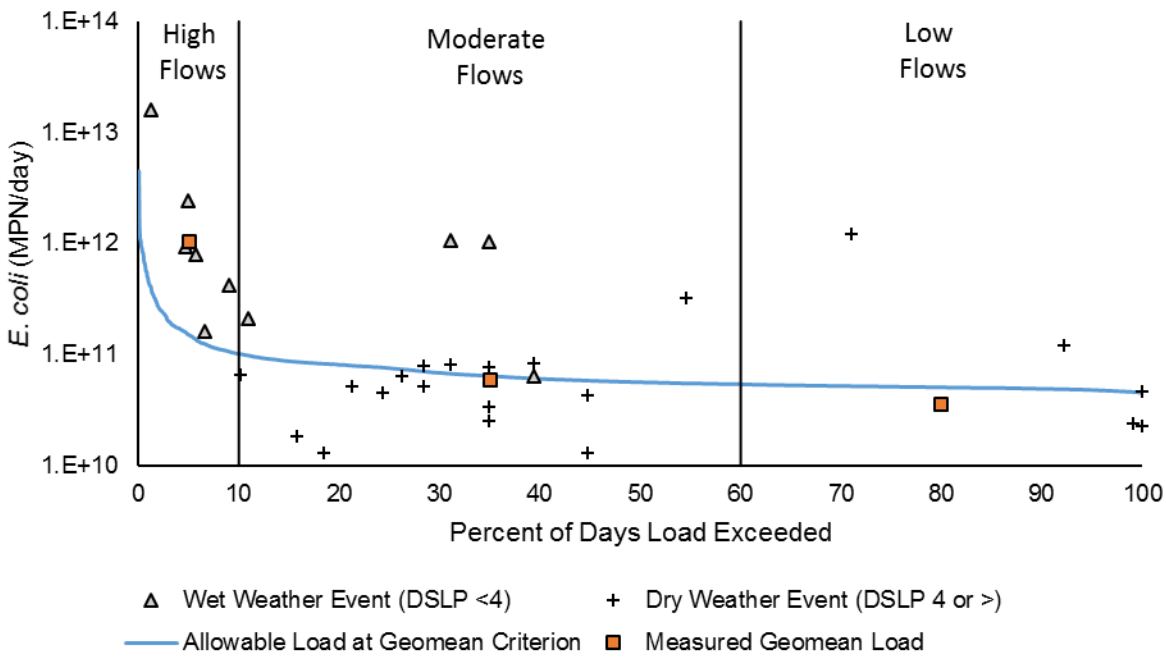

Figure 2-3 Load duration curve for station 18828, South Nolan Creek at 38th Street.

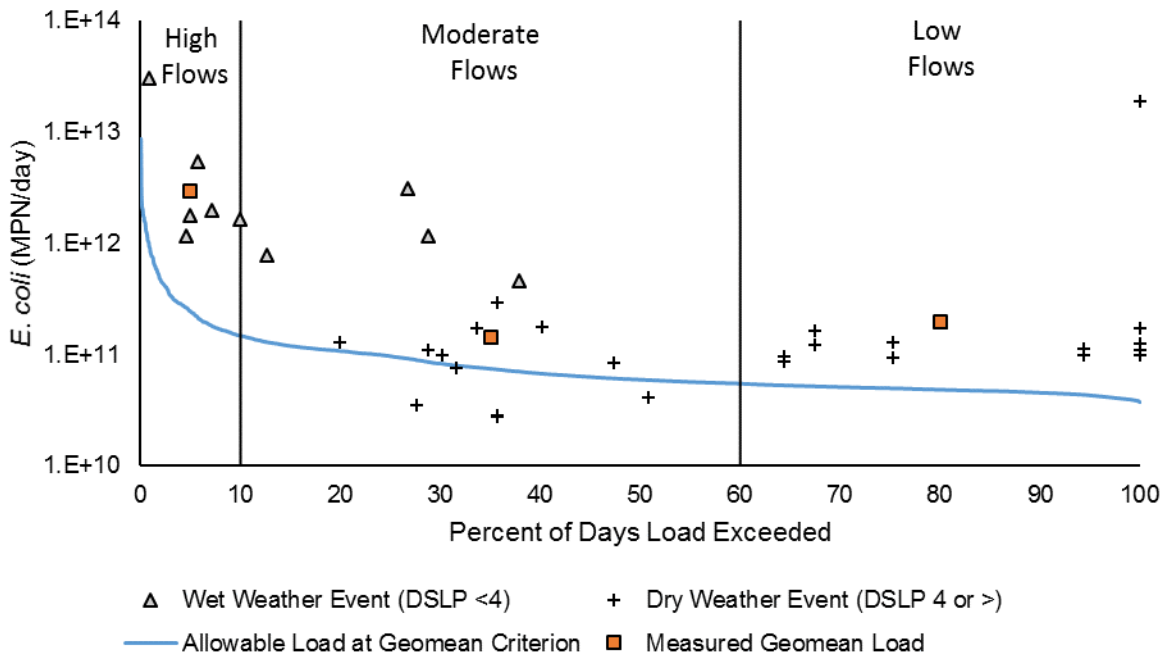

Figure 2-4 Load duration curve for station 11913, South Nolan Creek at Roy Reynolds Road.

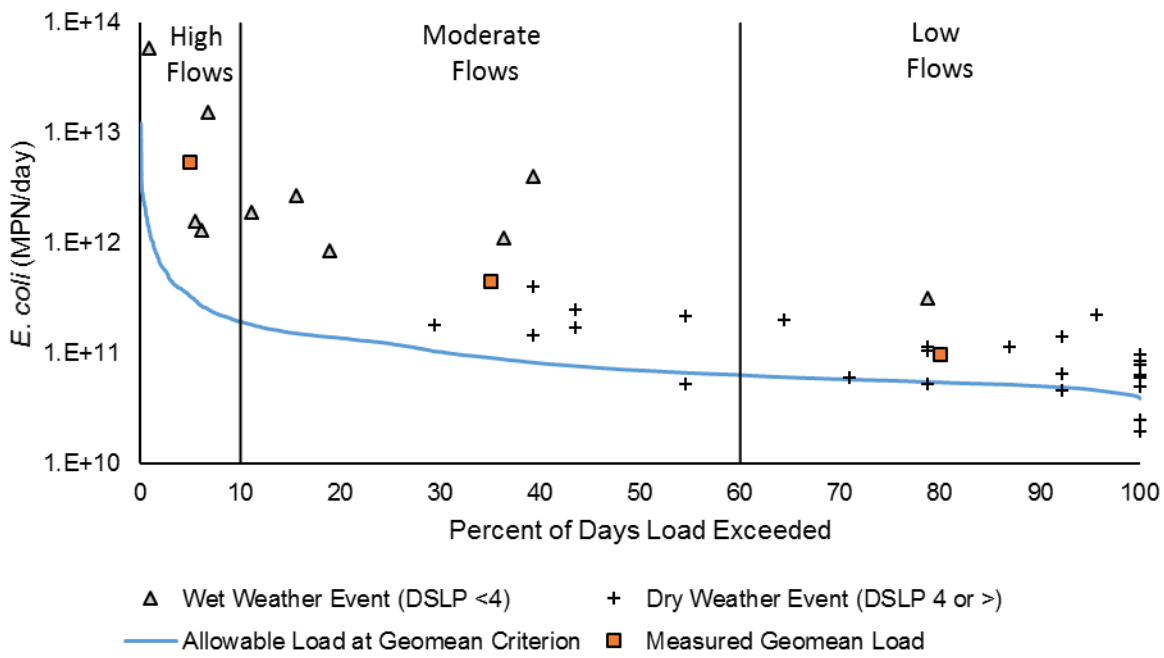

Figure 2-5 Load duration curve for station 11910, Nolan Creek at US 190.

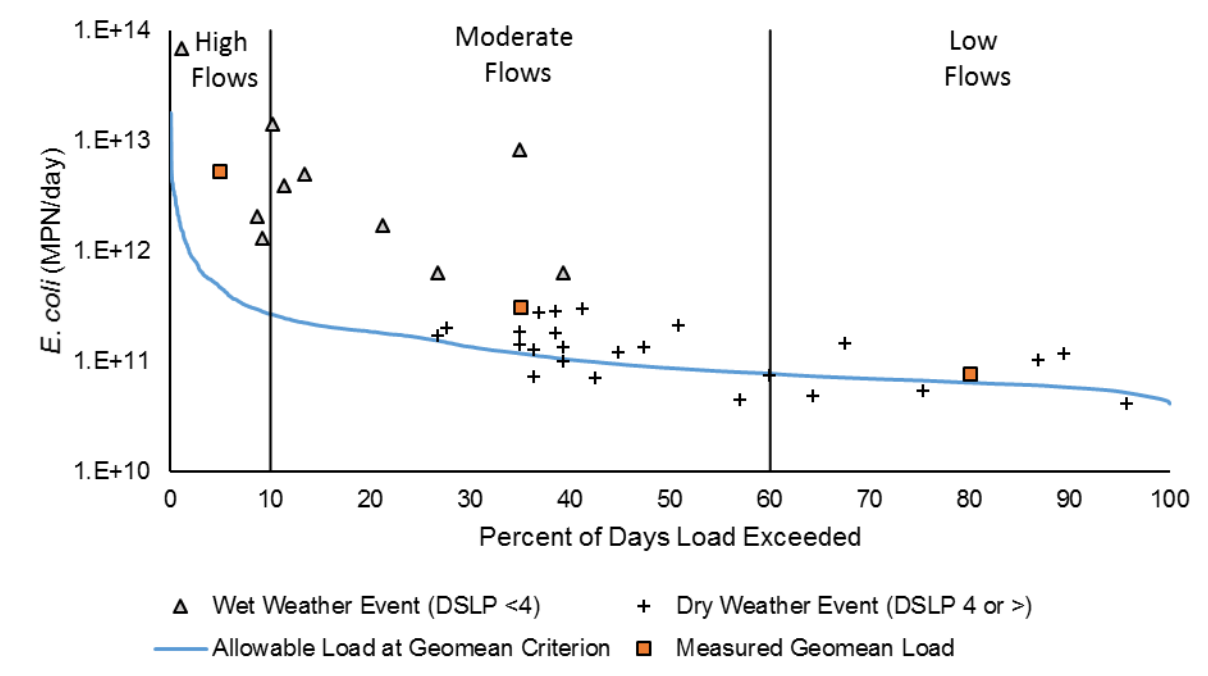

Figure 2-6 Load duration curve for station 11905, Nolan Creek at Backstrom Crossing.

For all four stations, measured bacteria loadings for high flows were associated with wet-weather events with all values exceeding the allowable loading based on the 126 MPN/100 mL criterion (Figures 2-3 – 2-6). For moderate flows, loadings during wet and dry events at all stations generally exceeded criterion loadings, except at station 18828. At station 18828, the most upstream station located along South Nolan Creek at 38th Street in the City of Killeen, most dry event samples collected under moderate flow conditions led to loadings below the criterion load. In almost all cases, loadings associated with wet-weather events lead to higher loadings than dry-weather events monitored under similar flow conditions. Similar to moderate flows, all stations, but 18828, indicated geometric mean loadings above the criterion loading level.

Estimated Load Reductions

To satisfy part of EPA's nine elements for watershed plans (EPA, 2008), estimates of percent reductions were calculated within each flow regime. This was done for bacteria by taking the geometric mean of measured values within each flow regime and calculating the percent difference in relation to the criterion (126 MPN/100 mL) and dividing that difference by the measured geometric mean concentration (Table 2-3). The highest estimated load reductions were noted during high flows as over 90 percent at all four stations. For moderate and low flows, no reductions were noted for station 18828 with negative reduction percentages. The highest percent reduction during moderate flows was noted at station 11910 for Nolan Creek at US 190. The highest percent reduction during low flows was noted at station 11913 on South Nolan Creek at Roy Reynolds Road between the City of Killeen and the City of Harker Heights. Of note at station 11913, one very high bacteria value occurred during low flows in association with a sample collected on July 10, 2013 with an *E. coli* concentration of 77,000 MPN/100 mL. If this

value of 77,000 MPN/100 mL is removed, the geometric mean at station 11913 decreases from 509 to 335 MPN/100 mL during low flow conditions leading to an estimated percent reduction of 62 percent.

Table 2-3 Geometric mean concentrations of measured bacteria values by flow regime and estimated percent reductions needed to meet the primary contact recreation criterion of 126 MPN/100 mL for four stations along Nolan Creek/South Nolan Creek. Negative percent reductions indicate the criterion is already met and reductions are not necessary.

Station	High Flows (0-10%)		Moderate Flows (10-60%)		Low Flows 60-100%)	
	Geometric Mean *E. coli* (MPN/100 mL)	Estimated Percent Reduction	Geometric Mean *E. coli* (MPN/100 mL)	Estimated Percent Reduction	Geometric Mean *E. coli* (MPN/100 mL)	Estimated Percent Reduction
18828	865	85%	116	-8%	88	-44%
11913	1521	92%	243	48%	509	75%
11910	2049	94%	616	80%	227	44%
11905	1405	91%	326	61%	149	16%

SECTION 3

Pollutant Sources

While LDCs depict the flow regimes under which excessive loadings occur, they can do little beyond aiding in differentiating between point and nonpoint sources. Use of SELECT in combination with LDCs aids in identifying more specifically potential sources based on watershed characteristics. To produce an overview of potential bacteria loadings by source for a watershed, SELECT relies on land-use classification data integrated with information regarding the soils, the layout of the stream network, human population and animal densities, as well as the location and discharge of point sources, such as municipal wastewater treatment facilities (WWTFs). Many of the inputs used for SELECT were identified in the data inventory and source survey reports completed for this project (McFarland and Adams, 2015a; 2015b). Input from local stakeholders was also important in deriving the types and densities of potential pollution sources and feedback on preliminary inputs was obtained from stakeholders at the September 25, 2014 meeting of the Nolan Creek Partnership. For the Nolan Creek/South Nolan Creek watershed, the following major sources were identified for inclusion in SELECT:

Regulated Sources

- Municipal Wastewater Discharges
- Urban Stormwater Runoff

Non-Regulated Sources

- Cattle
- Sheep/Goats
- Horses (including ponies, mules, burros, and donkeys)
- Feral Hogs
- Deer
- Dogs
- On-Site Sewage Facilities (often referred to as septic systems)

Some bacteria sources identified but not included due the lack of needed density information include small wildlife, such as birds, raccoons, opossums, and skunks. For small wildlife, the appropriate animal density and fecal production data are not yet available for integration into SELECT (Borel et al., 2015).

For most potential sources, such as livestock, an animal density and fecal production rate is related with particular types of land cover to estimate the distribution of animals in the watershed. To aid in targeting areas and potential pollution sources across the landscape, SELECT does not just look at the watershed as a whole, but divides the watershed into multiple smaller sub-watersheds based on elevation changes along tributaries and the mainstem of the river. To delineate subwatersheds, the ArcView Soil and Water Assessment Tool (AVSWAT; Di Luzio et al., 2002; 2004) was employed. A stream threshold of 200 acres was used for the initial delineations. A few watersheds were then manually combined to obtain a more even distribution of subbasin areas resulting in 45 sub-watersheds varying in size from 889 to 2,579 acres with an average subwatershed size of 1,618 acres (Figure 3-1).

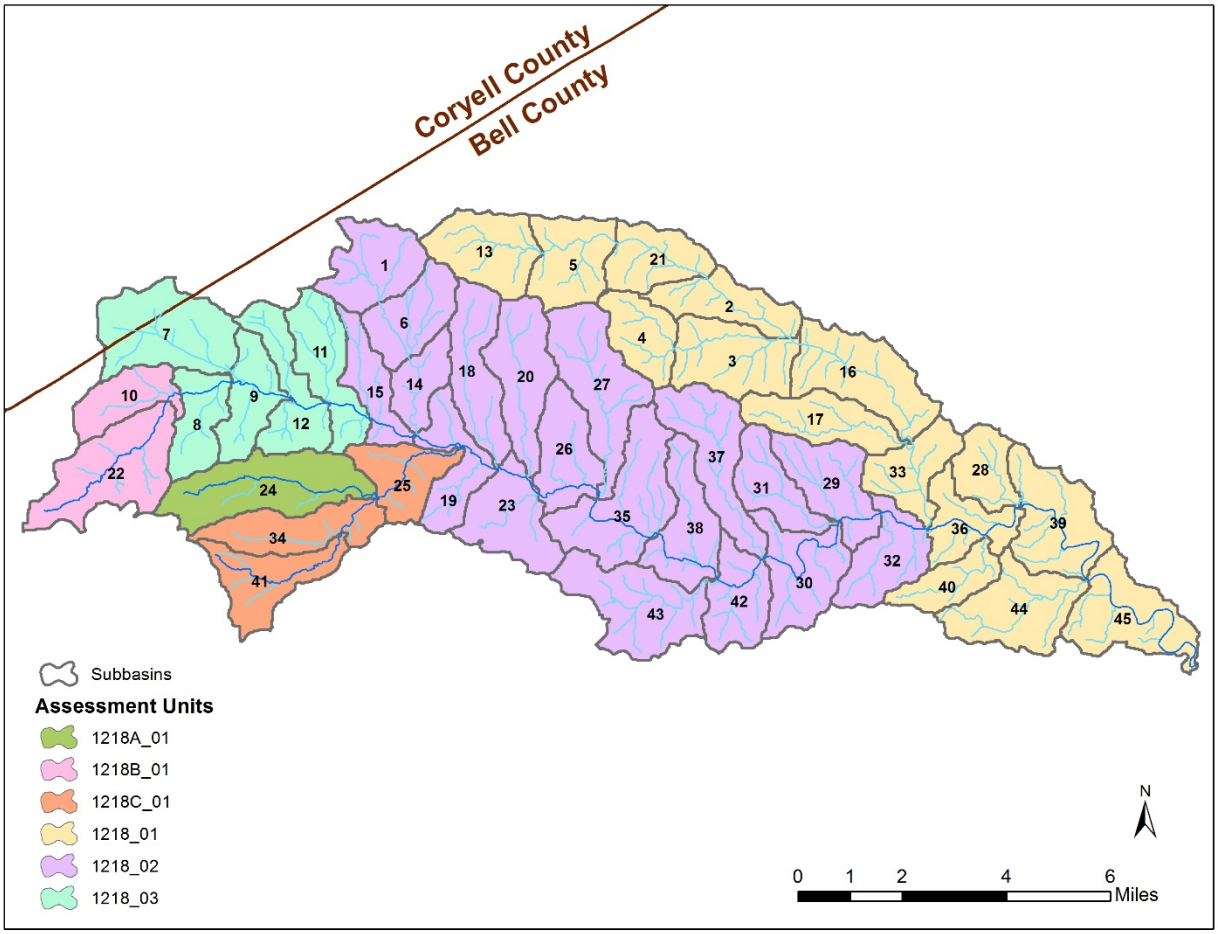

Figure 3-1 Delineated subwatersheds for Nolan Creek/South Nolan Creek watershed. Subwatersheds delineated using AVSWAT.

SELECT Methodology

The analysis of potential loadings using SELECT was conducted on a 30-meter-by-30-meter spatial resolution distributing each source over suitable areas within the watershed and aggregating potential loadings at the subwatershed level. For most nonpoint sources, such as livestock or deer, suitable areas were defined by land-use cover with potential bacteria loadings estimated based on the density of the source (for example, number of animals per acre) and the fecal production rate for that source. While SELECT was developed for rural watersheds, the urban area, as represented by point sources from WWTFs and municipal separate storm sewer system (MS4) areas, can also be considered with some modifications (e.g., Ling et al., 2012). For WWTFs, potential bacteria loadings are based on the discharge rate and location. Urban areas are a bit more challenging with SELECT due to the large variety of potential sources. In using SELECT, potential loadings from urban area have been associated with a runoff amounts and the land area associated with impervious cover (e.g., Ling et al., 2012).

Fecal production rates for sources followed previous applications of SELECT (see Teague et al., 2009; Brazos River Authority and Espey Consultants, 2010; and Borel et al., 2012), which were based primarily on information provided in EPA guidance for *E. coli* (USEPA, 2001; Table 3-1). If only fecal coliform production rates were available, these were converted to *E. coli* production rates by multiplying fecal coliform rate by 0.5 (Doyle and Erikson, 2006).

Table 3-1 Production rates of *E. coli* by source. Production rates generally based on values for raw waste unless otherwise specified. Production rates are in colony forming units (cfu) per day. Source: EPA (2001) unless otherwise noted.

Source	Production Rate, *E. coli* (cfu/day) [a]	Load Calculation (cfu/day)
Municipal Wastewater Discharges	126 cfu/100 mL[b]	Production rate times permitted discharge in milliliters
Urban Stormwater	2.87×10^2 to 1.04×10^6 [c]	Estimated runoff volume times *E. coli* loading associated with impervious cover from 1 to 100 percent of land area
Cattle	10×10^9 cfu/day * 0.5	Production rate times number of cattle
Sheep/Goats	1.2×10^{10} cfu/day * 0.5	Production rate times number of sheep & goats
Horses	4.2×10^8 cfu/day * 0.5	Production rate times number of horses
Feral Hogs	1.1×10^{10} cfu/day * 0.5	Production rate times number of hogs
Deer	3.5×10^8 cfu/day * 0.5	Production rate times number deer
Dogs	5×10^9 cfu/day * 0.5	Production rate times number of dogs
On-Site Sewage Facilities	10×10^6 cfu/100 mL * 0.5	Production rate times potential failure discharge amount

a. Production rate values multiplied by 0.5 are in units of fecal coliform original and converted to *E. coli* using a conversion factor suggested by Doyle and Erikson (2006).

b. For permitted dischargers, the criterion of 126 cfu/100 mL associated with primarily contact recreation was used as the maximum potential production rate for bacteria in potential load calculations.

c. Production rates for urban stormwater runoff based on estimates from a study by PBS&J (2000) with the curve adjusted for a zero intercept as the percent impervious cover reaches zero.

Land use/land cover data were obtained from the 2011 National Land Cover Database. The 2011 National Land Cover Database applies a 30 meter spatial resolution and is based on circa 2011 Landsat satellite data (USGS, 2014a).

Regulated Sources

Municipal Wastewater Discharges

There are eight permitted outfalls that discharge within the Nolan Creek/South Nolan Creek watershed (Table 3-2, Figure 3-2). Of note, the Bell County Water Control and Improvement District (WCID) No. 1 - Plant 3 facility, also known as the "South Plant", is physically located south of the watershed on 8290 Chaparral Road in Killeen, but discharges to South Nolan Creek within the City of Nolanville. Managers at the WCID No. 1 - Plant 3 have indicated that if approved as part of an upcoming permit renewal, portions of the wastewater from this plant may be discharged to Trimmier Creek, outside the Nolan Creek/South Nolan Creek watershed, but emphasized that this potential change as of August 2015 has not yet been approved. Bell County WCID No. 1 also runs a composting facility, which is located outside the watershed boundary, but processes biosolids from all three of its WWTFs. Permitted discharge amounts and location of each outfall are indicated in Table 3-2. Within SELECT, the maximum permitted discharge and the *E. coli* concentration permit limit of 126 cfu/100 mL was applied to each subwatershed with a WWTF outlet (Table 3-2 and Figure 3-3).

Table 3-2 Potential loading rates and subwatershed location for permitted dischargers within the Nolan Creek/South Nolan Creek watershed.

Facility Name	Subwatershed Location of Outfall	Permit #	Permitted Discharge (million gallons per day, MGD)	Potential Daily E. coli Loading (cfu/day)
Temple Belton Regional WWTF	45	WQ0011318001	10	4.74E+10
Bell County WCID No. 3 WWTF	38	WQ0010797001	0.675	3.20E+09
City of Harker Heights WWTF	23	WQ0010155001	3	1.42E+10
Bell County WCID No. 1 WWTF (Main Plant)	15	WQ0010351002	18	8.52E+10
Bell County WCID No. 1 (Plant 2)	15	WQ0010351003	6	2.84E+10
Bell County WCID No. 1 (Plant 3, South Plant)	35	WQ0014387001	6	2.84E+10
Universal Services Ft Hood WWTF	10	WQ0013358001	0.09	4.26E+08
BLORA WWTF	16	WQ0014994001	0.03	1.42E+08

a. Loadings for permitted dischargers were calculated as *E. coli* (cfu/day) = permitted MGD*(126 cfu/100 mL)*(10^6 gallons/MGD)*(3758.2 mL/gallon).

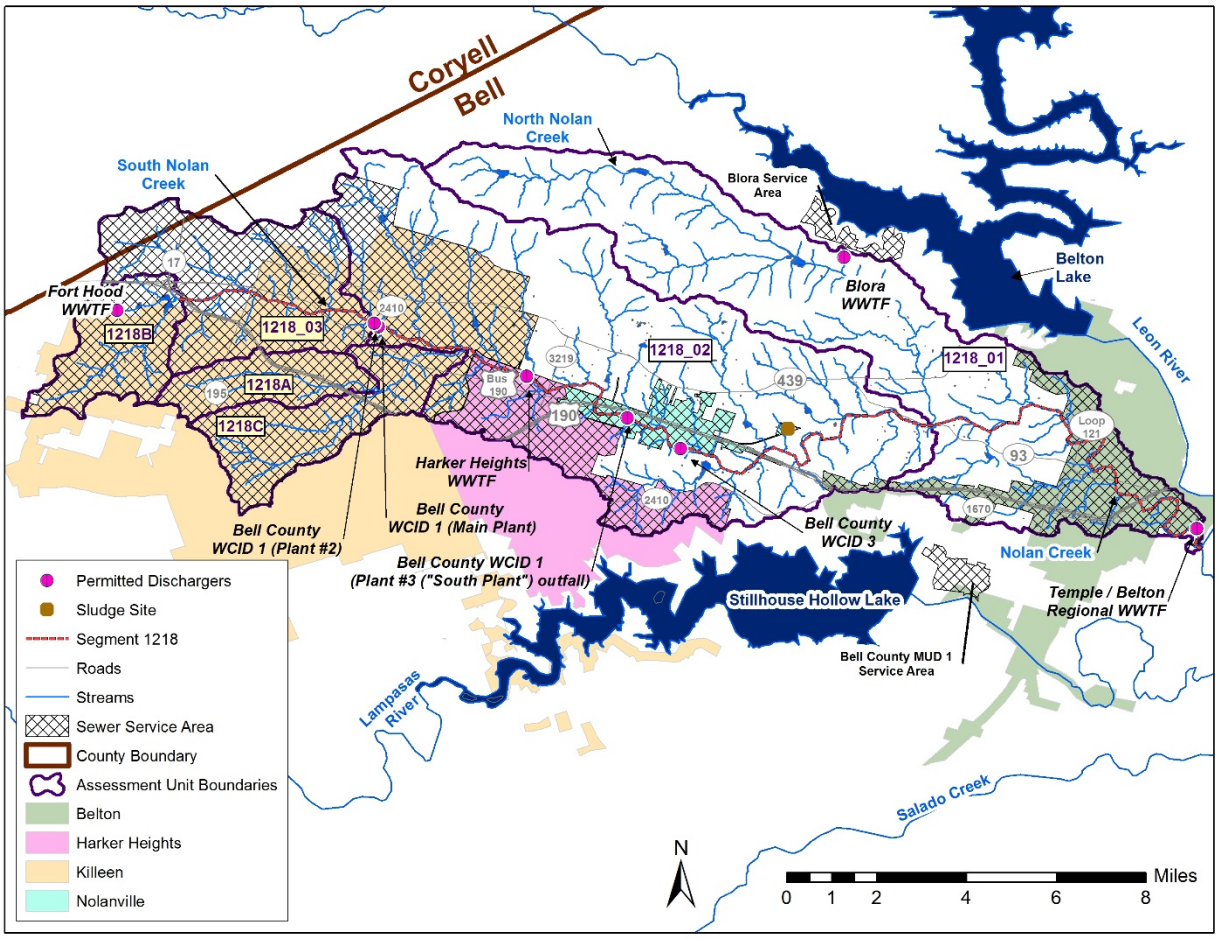

Figure 3-2 Location of WWTF discharges and service area for wastewater collection within the Nolan Creek/South Nolan Creek watershed. Note: The service area was based on certificates of convenience and necessity (CCNs) and municipal boundaries. The service area for some of these dischargers extends outside the watershed boundaries, largely following municipal boundaries for the cities of Killeen and Harker Heights. Location of WWTF discharges obtained from TCEQ GIS layer of permitted wastewater outfalls, publication date March 12, 2014.

The distribution of potential loadings from WWTFs weights the various subbasins based on the discharge amounts associated with the location of each point source (Figure 3-3). The maps from SELECT breakout loadings into relative cateogories across subbasins with the lowest loadings noted in shades of green, moderate loadings in yellow to orange, and the highest loadings in shades of red. For potential loadings, the *E. coli* criterion of 126 cfu/100 mL is assumed, but in reality, WWTF discharges generally have a much lower concentrations of bacteria, with geometric means of less than 20 cfu/100 mL reported for all eight facilities based data from the last five years.

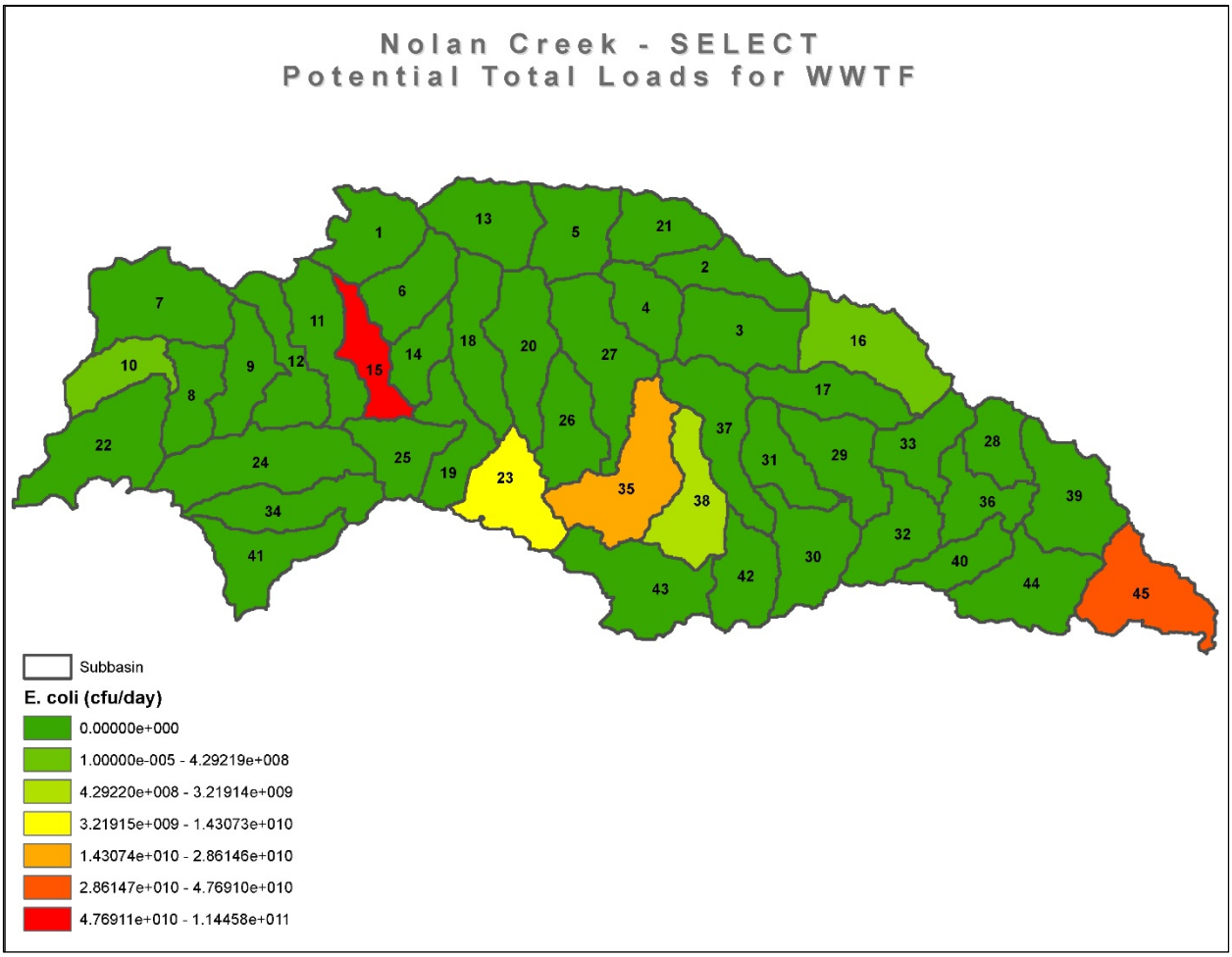

Figure 3-3 Distribution of potential *E. coli* loads from WWTFs by subbasin within the Nolan Creek/South Nolan Creek watershed.

Urban Stormwater Runoff

Stormwater runoff from urban areas falls under MS4 permitting regulations with the permitted "Urbanized Area" defined by the U.S. Census Bureau as areas with populations greater than 50,000 that have an overall population density of at least 1,000 people per square mile (Figure 3-4). Within these urbanized areas, the percentage of impervious cover is often related to developed land use/land cover. Because SELECT focuses on land use, the potential loadings from urban stormwater runoff were not limited to the MS4 boundaries, but focused on the impervious cover within each subbasin.

From the National Land Cover Database for 2011, about 40 percent of the Nolan Creek/South Nolan Creek watershed is comprised of developed areas (Figure 3-5). The intensity of development varies greatly. Within the National Land Cover Database, developed land is considered a mixture of constructed materials and vegetation with impervious cover ranging from less than 20 percent in developed, open space to 80 percent or greater in high intensity developed areas (USGS, 2014a). For low intensity developed areas, impervious covers accounts for 20 to 49 percent of total cover, while in medium intensity developed areas, impervious cover

accounts for 50 to 79 percent of total cover (USGS, 2014a). For reference, the percent of developed land by subcategory within each assessment unit (AU) within the Nolan Creek/South Nolan Creek watershed is given in Table 3-3. The most high intensity developed area is found in the area of AUs 1218_03 and 1218A.

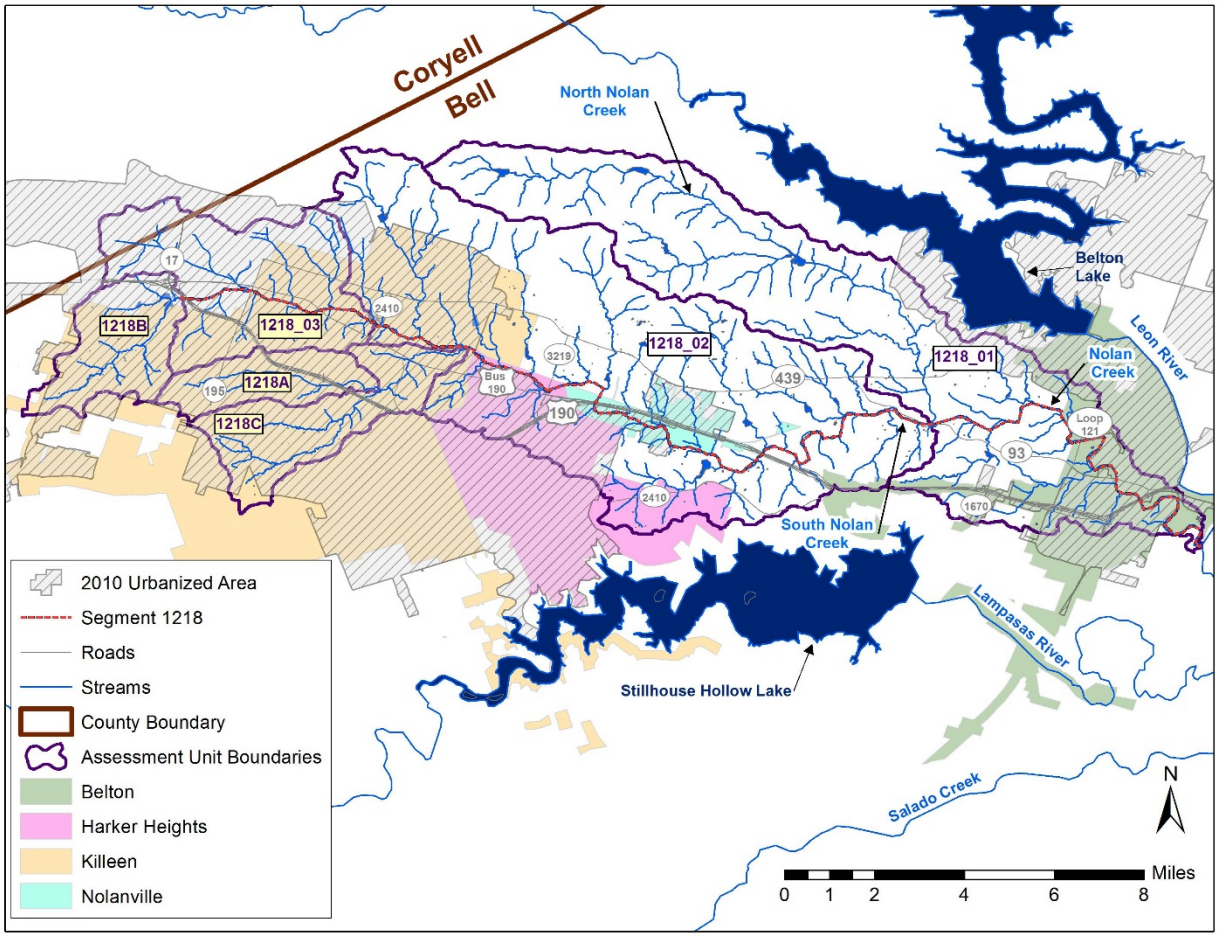

Figure 3-4 Location of MS4 areas within the Nolan Creek/South Nolan Creek watershed. For the watershed, the MS4 areas for cities include the 2010 Census Data for urbanized areas and extend to municipal boundaries.

To estimate the relative potential loadings from urban stormwater runoff, the amount of impervious cover was estimated using the middle of the range for impervious cover noted for each subcategory of developed land as noted by the USGS (2014a). The percent impervious cover assumed was 90 percent for high intensity developed land, 65 percent for medium intensity developed land, 35 percent for low intensity developed land, and 10 percent for developed open space. For example, if a 200 acre subbasin was 30 percent high intensity developed land and 20 percent medium intensity developed land and the rest of the land area in uses other than developed, the impervious cover was estimated to cover 80 of the 200 acres or 40 percent of the subbasin.

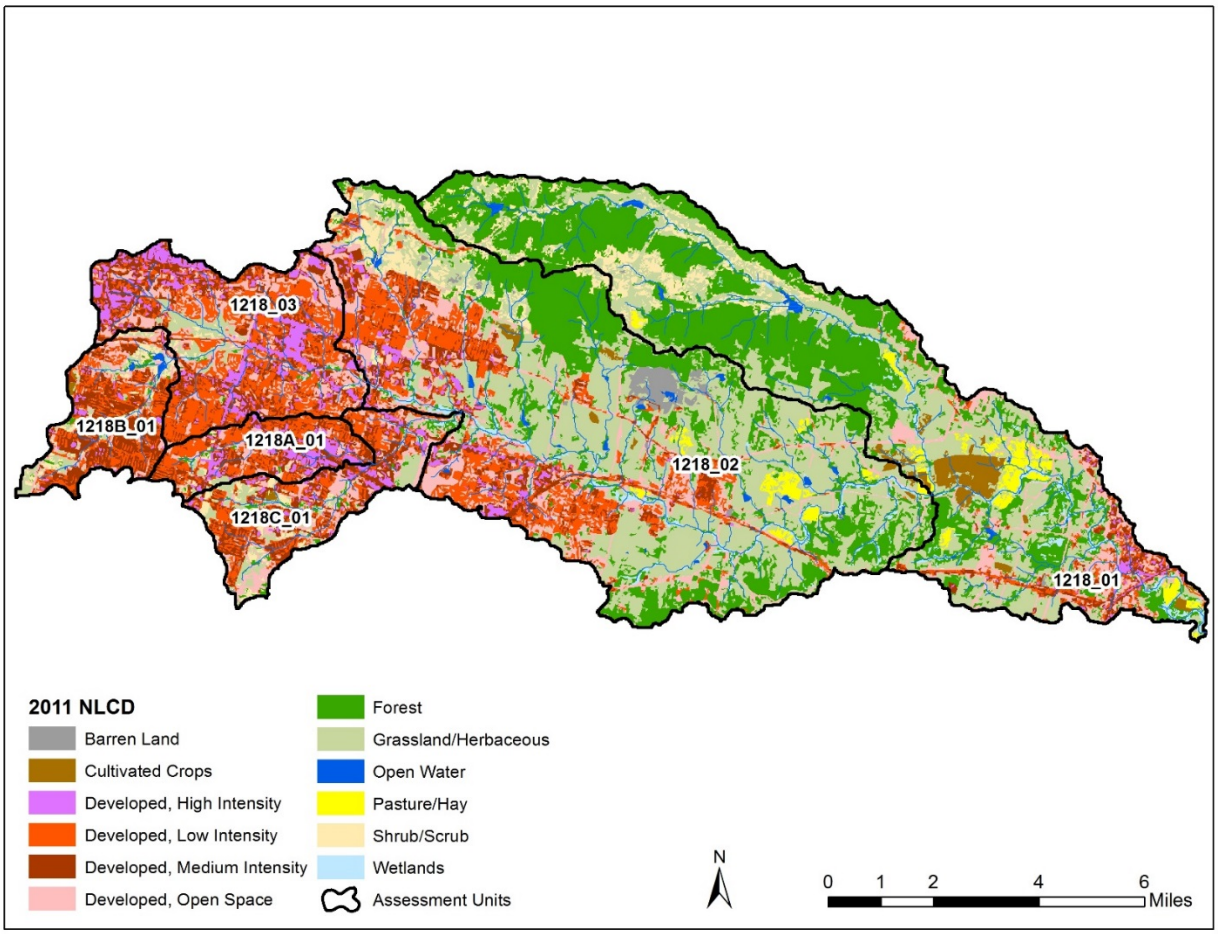

Figure 3-5 Land use/land cover for the Nolan Creek/South Nolan Creek watershed showing developed subcategories. Source: 2011 National Land Cover Database (USGS, 2014a).

Table 3-3 Percent developed land by subcategory and number of total acres of developed land within each AU of the Nolan Creek/South Nolan Creek watershed. Source: 2011 National Land Cover Database (USGS, 2014a).

Developed Subcategory	1218_01	1218_02	1218_03	1218A	1218B	1218C
Developed, High Intensity	6%	6%	17%	18%	4%	8%
Developed, Medium Intensity	18%	18%	24%	30%	43%	32%
Developed, Low Intensity	19%	37%	36%	37%	34%	30%
Developed, Open Space	57%	39%	22%	15%	20%	30%
Total Acres Developed	**3,106**	**9,913**	**7,488**	**2,430**	**2,867**	**3,391**

The bacteria production rate was then estimated for each subbasin based on the estimated percent impervious cover using the following equation derived by PBS&J (2000):

$$FC = [10^{(4.03 + 0.0229*(IC))}]$$

where

FC = fecal coliform in cfu/100 mL and

IC = percent impervious cover

The equation above was modified to indicate zero loadings when the percent impervious cover was zero in a subbasin by subtracting 10,722. This still provided the basic form of the equation with increasing event mean concentrations (EMCs) of bacteria in stormwater runoff as the percent of impervious cover in a subbasin increased. As the purpose of SELECT was to get at potential relative loadings between subbasins, it made sense that loadings from urban runoff should be zero rather than producing an artificial loading.

The production rate for FC was then multiplied by 0.5 to estimate the production rate of *E. coli* within a subbasin. The equation above provides an estimate of the EMC of bacteria associated with stormwater runoff. To get at an estimate of the volume of runoff, a curve number approach was applied using standard equations on the impervious land cover within each subbasin for a typical storm event (McCuen, 1982). A curve number of 98 was used for these impervious surfaces. Volume estimates assumed average antecedent moisture conditions. Historical daily precipitation data from 1981-2010 were reviewed and a typical storm event for the City of Killeen was estimated as 0.45 inches.

Potential loading from urban stormwater are shown for the areas with the highest percent impervious cover (Figure 3-6). Of note, the subbasins with the highest potential loading from urban stormwater based on SELECT appear to be associated with assessment unit areas (1218_03 and 1218A_01, see Figure 3-1) that are not noted as impaired for bacteria (TCEQ, 2013).

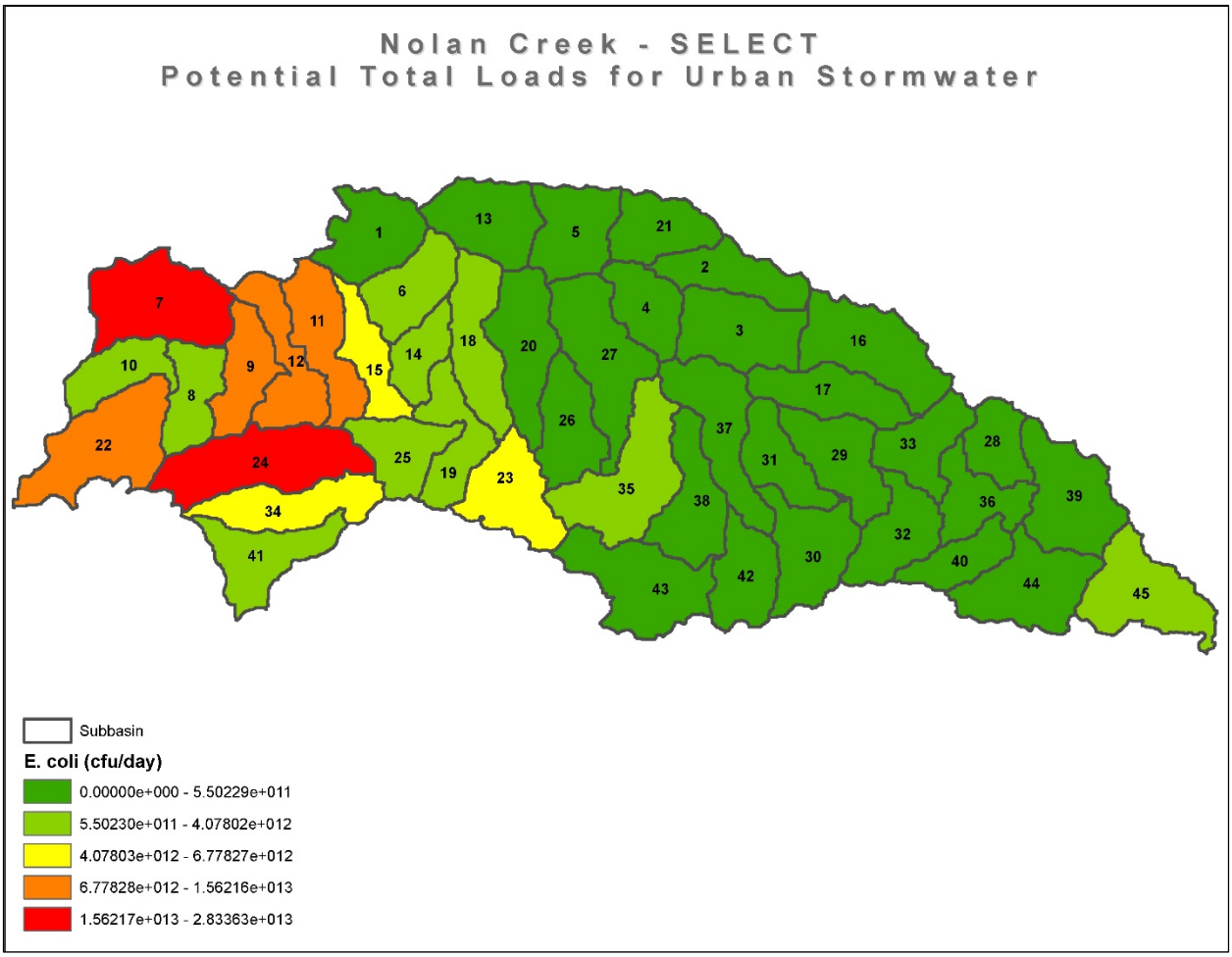

Figure 3-6 Distribution of potential *E. coli* loads from urban stormwater runoff by subbasin within the Nolan Creek/South Nolan Creek watershed.

Non-Regulated Sources

Livestock

For livestock, county level data are generally used to estimate livestock numbers as the best available information (see Teague et al., 2009). For Bell County, the latest USDA Census of Agriculture conducted by the National Agriculture Statistics Service (NASS) in 2012 notes cattle followed by goats and sheep as the dominant types of livestock (USDA-NASS, 2014). Horses and ponies combined with estimates of mules, burros, and donkeys were also considered another prominent livestock categories when SELECT was run (Table 3-4). Poultry, while noted as a major livestock category within Bell County with almost 14,000 chickens, primarily layers, was excluded as a category for the Nolan Creek/South Nolan Creek watershed within SELECT as no poultry houses are located within the watershed area. Hogs and pigs were also excluded from SELECT as there are no large hog facilities within the watershed.

Table 3-4 Livestock census estimates for Bell County. Source: USDA-NASS (2014).

Category	Bell County Total Inventory Number
Cattle & Calves	34,922
All Poultry	13,898
All Goats	12,813
Sheep & Lambs	4,269
Horses & Ponies	2,903
Mules, Burros, & Donkeys	832
Hogs & Pigs	750

Livestock estimates within SELECT were then distributed by category across what were considered suitable land covers. For example, cattle grazing is most often associated with grassland herbaceous and pasture hay land covers. Because the land use for Bell County overall is quite different from the land use within the Nolan Creek/South Nolan Creek watershed (see Table 3-5), livestock numbers for Bell County were weighted based on the land covers most often associated with each to determine an estimate of livestock numbers within the Nolan Creek/South Nolan Creek watershed (Table 3-6).

Table 3-5 Comparison of land use/land cover for the Nolan Creek/South Nolan Creek watershed with Bell County. Source: 2011 National Land Cover Database (USGS, 2014a).

Category	Nolan Creek/South Nolan Creek Watershed (%)	Nolan Creek/South Nolan Creek Watershed (acres)	Bell County (%)	Bell County (acres)
Developed	40.1	29,196	13.3	92,480
Barren	0.8	590	0.3	2,086
Forest	22.6	16,708	17.5	121,684
Shrub/Scrub	4.2	3,040	4.3	29,899
Grassland Herbaceous	26.8	19,517	32.0	222,508
Pasture Hay	1.5	1,072	7.5	52,150
Cultivated Crops	1.4	991	19.0	132,114
Wetlands	1.8	1,337	2.9	20,165
Open Water	0.5	360	3.2	22,251
Totals	100.0	72,811	100.0	695,336

Table 3-6 Livestock estimates for the Nolan Creek/South Nolan Creek watershed. Based on 2012 Census of Agriculture for Bell County (USDA-NASS, 2014) and 2011 NLCD (USGS, 2014a).

Category	Estimated Animals in Bell County	Associated Land Use/Land Cover (LULC)	Land Area in Bell County represented by LULC (acres)	Land Area in Nolan Creek/South Nolan Creek Watershed associated with LULC (acres)	Estimated Animals in Nolan Creek/South Nolan Creek Watershed
Cattle & Calves	34,922	Grassland Herbaceous & Pasture Hay	274,658	20,589	2,618
Sheep & Goats	17,082	Grassland Herbaceous, Pasture Hay, Shrubland & Forest	396,342	37,297	1,607
Horses & Ponies and Mules, Burros, & Donkeys	3,735	Grassland Herbaceous & Pasture Hay	274,658	20,589	280

Another slight complication in using SELECT in a watershed with a large urban component is that within some municipal boundaries, there are areas of land that would be considered suitable for livestock grazing, but such a use would be prohibited by municipal ordinances. In running SELECT, suitable land use areas within municipal boundaries were masked out so livestock would not be distributed within municipalities. Of note, there are likely exceptions in some areas where livestock do occur within a municipal boundary. For example, based on the timing of annexation, land that was in agricultural use when annexed can be maintained in that use. For the watershed as a whole, these types of exceptions were considered rare and would be very minor contributors at the subwatershed scale currently being evaluated with SELECT.

Loadings for cattle were calculated as the number of head based on the adjusted number of cattle within the watershed times the production rate (see Tables 3-1 and 3-6). The *E. coli* loading from grazing cattle was then distributed within SELECT on grassland herbaceous and pasture/hay land covers, excluding municipal boundaries (Figure 3-7). The resulting stocking rate would be about 0.13 cows/acre on these land categories or 8 acres per cow. As might be anticipated, the largely rural areas between Nolanville and Belton indicated some of the largest potential loadings from cattle (Figure 3-6).

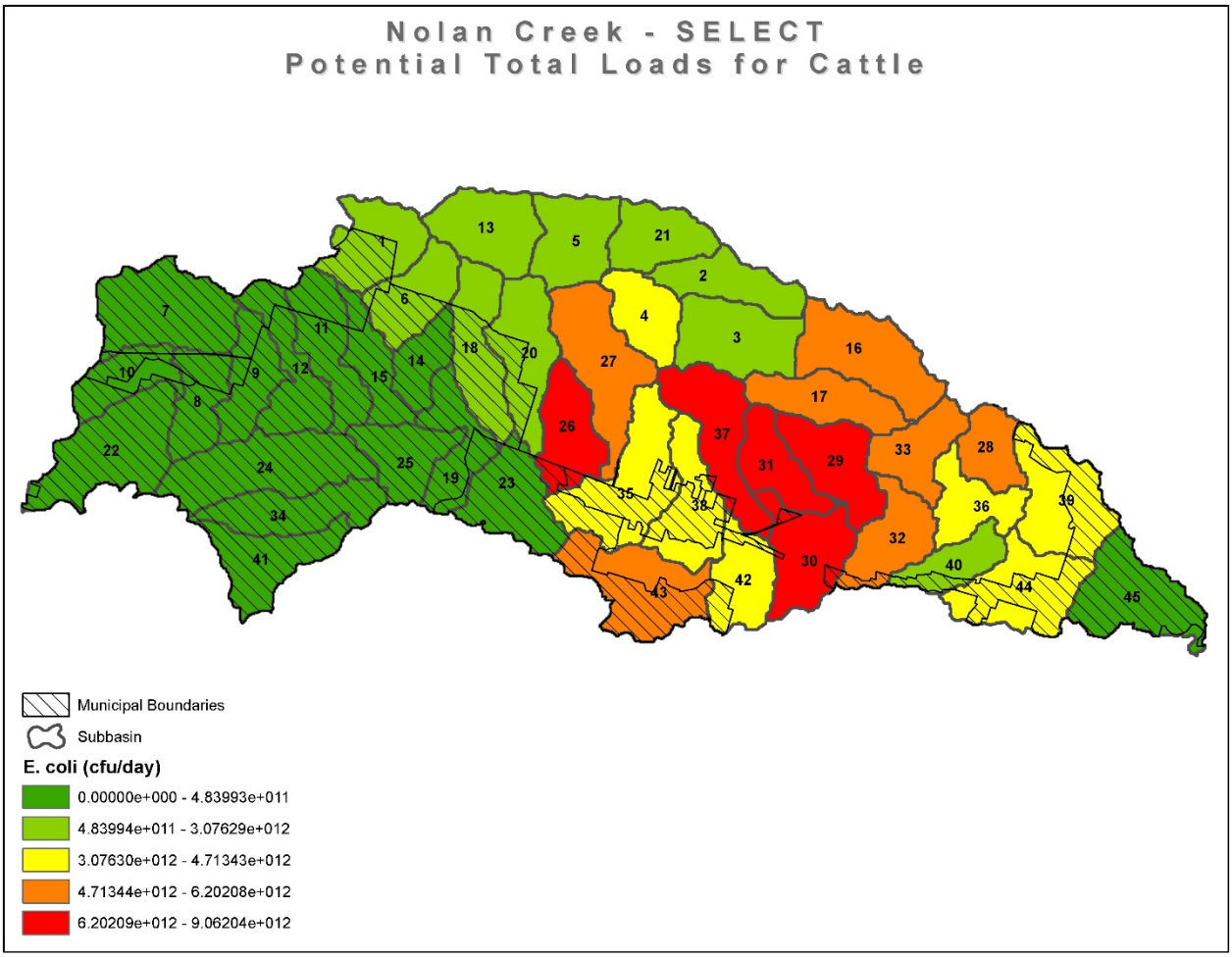

Figure 3-7 Distribution of potential *E. coli* loads from cattle by subbasin within the Nolan Creek/South Nolan Creek watershed. Municipal boundaries shown to indicate areas where livestock were excluded per city ordinances.

Similar to cattle, estimated sheep and goat numbers were obtained at the county level from USDA National Agricultural Statistics Service for Bell County and adjusted for the watershed as shown in Table 3-6. Loadings for sheep and goats were calculated as the adjusted number of head times the production rate (see Table 3-1) and distributed on the land-use categories of grassland/herbaceous, pasture/hay, shrub land, and woodland within the watershed, excluding the area within municipal boundaries (Figure 3-8). Based on the difference in land-use categories associated with sheep and goats than cattle, a higher density, and, thus, potential loadings were noted in subbasins associated with woodland.

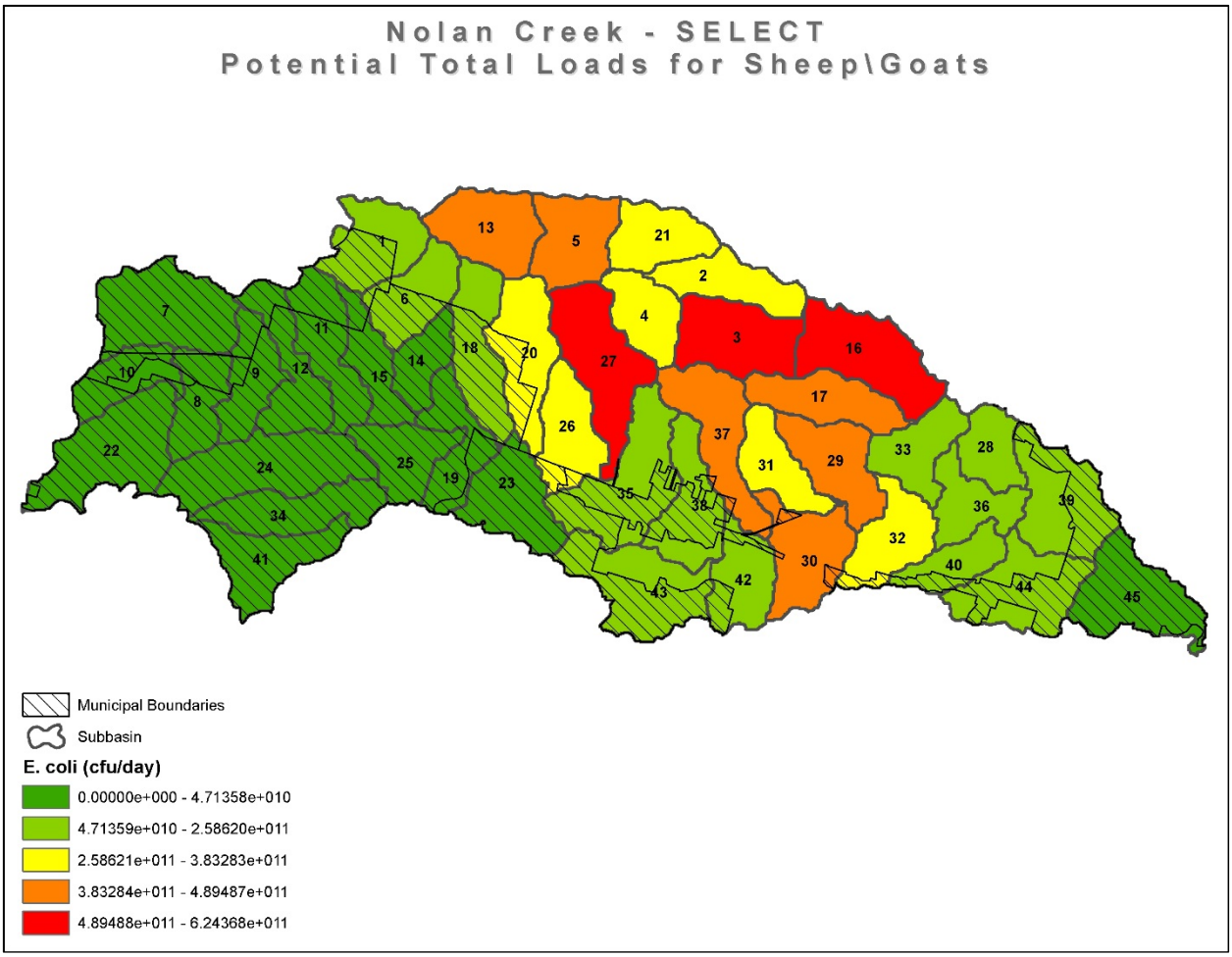

Figure 3-8 Distribution of potential *E. coli* loads from sheep and goats by subbasin within the Nolan Creek/South Nolan Creek watershed. Municipal boundaries shown to indicate areas where livestock were excluded per city ordinances.

Ponies, mules, burros, and donkeys were grouped with horses into one category within SELECT and estimated numbers were distributed across the area associated with grassland herbaceous and pasture hay, again excluding municipal boundaries (Figure 3-9). Because the same land-use categories were associated with horses as with cattle, the distribution pattern for the two sources looks similar (Figures 3-7 and 3-9), but the range of potential loadings varies. Higher potential loadings were associated with cattle than horses, because there were larger cattle numbers than horses (see Table 3-6).

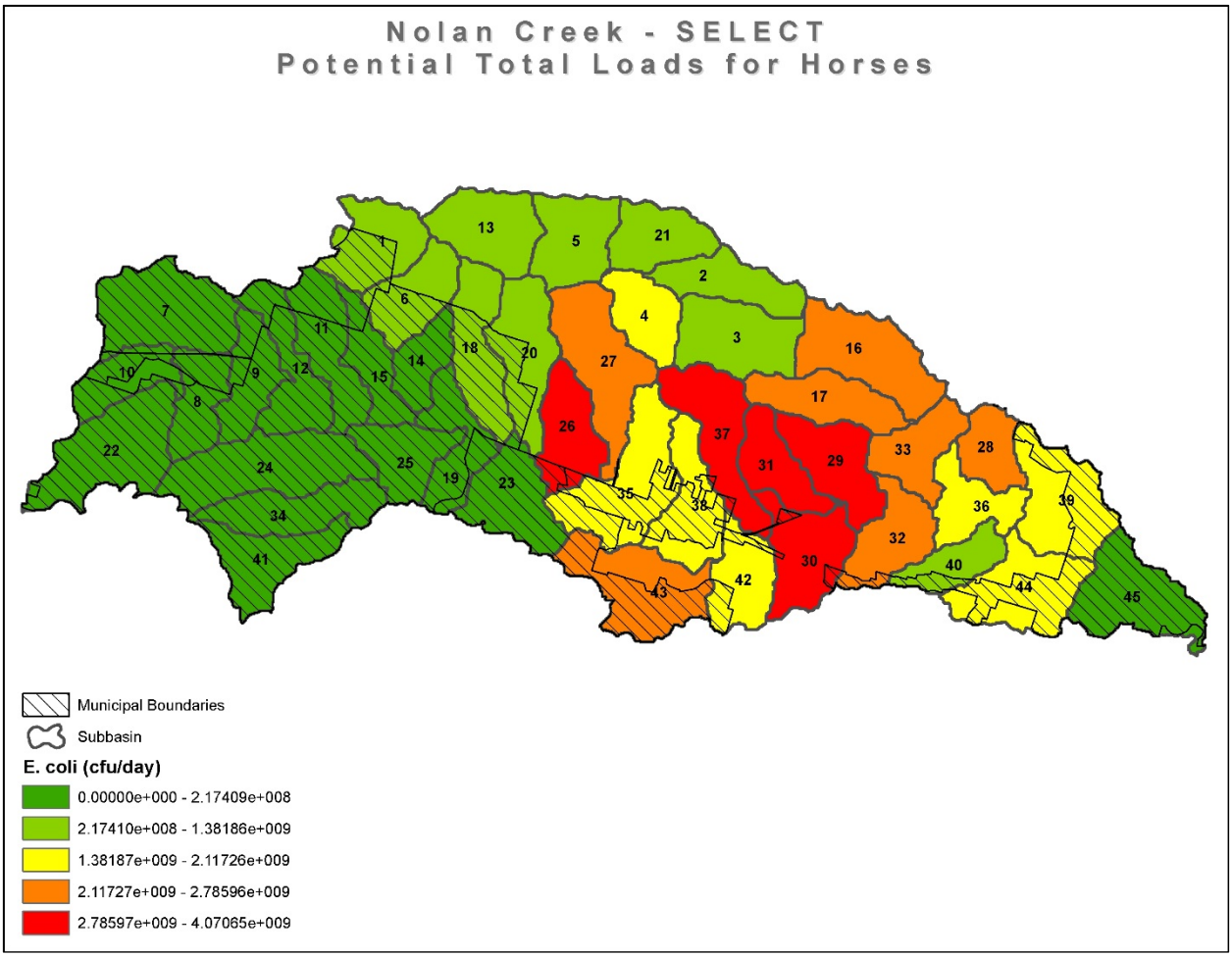

Figure 3-9 Distribution of potential *E. coli* loads from horses by subbasin within the Nolan Creek/South Nolan Creek watershed. Note: Horses represents a combination of horses, ponies, mules, burros, and donkeys. Municipal boundaries shown to indicate areas where livestock were excluded per city ordinances.

Feral Hogs

Feral hogs, while not natural wildlife, are invasive, unmanaged animals that are found throughout Texas and can contribute bacteria to streams in a manner similar to native wildlife. Feral hogs are classified by the Texas Parks and Wildlife Department (TPWD) as unprotected, exotic, non-game animals. Feral hogs are noted for moving in groups along waterways. Particularly in times of drought, feral hogs will congregate near perennial water sources to drink and wallow (Taylor, 2003). While generally not found in urban areas, in rural areas of Texas hog densities have been estimated to range from 20 to 54 acres per hog (Borel et al., 2012). For feral hogs, a density of 30 hogs per square mile or 0.05 hogs/acre is considered typical (Taylor, 2003; Hone, 1988; and Tate, 1984). Feedback from stakeholders indicated that the number of feral hogs in the watershed was very low, particularly in the urban areas. Feral hog wallows have been noted within the area of North Nolan Creek, which is largely comprised of forest and grassland (see Figure 1-2). Assuming feral hogs do not reside within developed areas or on open water, the number within the Nolan Creek/South Nolan Creek watershed was estimated 0.03 hogs/acre

times the remaining land area (43,255 acres; see Table 1-1) as 1,298 feral hogs. This density of 0.03 hogs/acre matches that used in adjoining watershed of the Lampasas River when applying SELECT (Prcin et al., 2013).

Total loadings for feral hogs were calculated as the total number of feral hogs in the watershed times the *E. coli* production rate (see Table 3-1). Because feral hogs are noted for moving in groups along waterways, and particularly in times of drought and will aggregate near perennial water sources to drink and wallow (Taylor, 2003), SELECT applies the loading of *E coli* associated with feral hogs uniformly across all land uses, but open water and developed areas, within a 100-meter buffer around the stream network (Figure 3-10). The municipal boundaries are overlaid on the SELECT output for feral hogs to give an indication of the location of developed or urban areas.

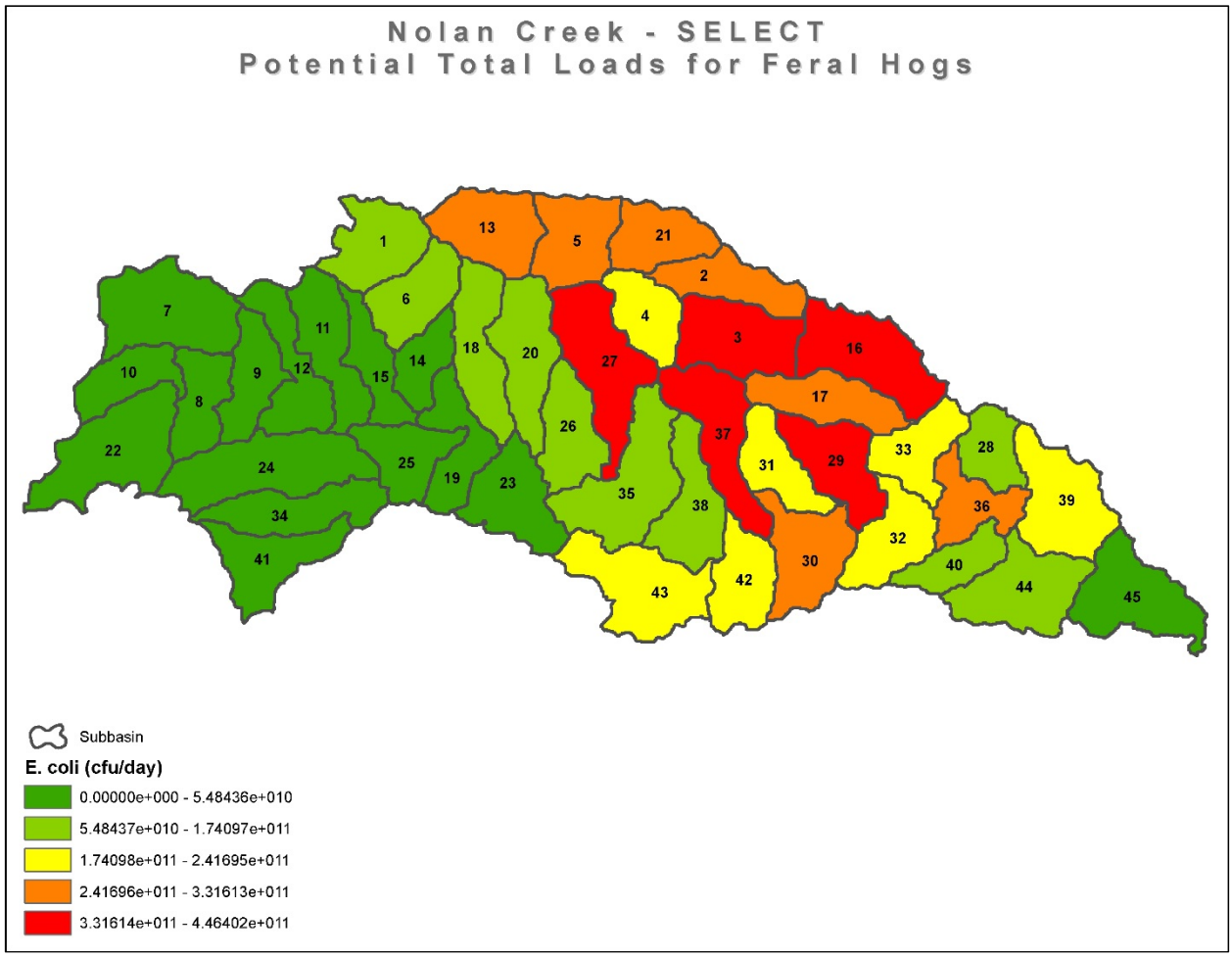

Figure 3-10 Distribution of potential *E. coli* loads from feral hogs by subbasin within the Nolan Creek/South Nolan Creek watershed.

Deer

For deer, a density of 12.3 deer per 1,000 acres or about 81 acres per animal was applied in SELECT based on survey data obtained from the TPWD for the Cross Timbers Ecoregion (TPWD, 2012). *E. coli* loads for deer were estimated based on potential loads indicated in Table 3-1. Within SELECT, deer were distributed across the land uses of woodland, shrubland, and near riparian forest (Figure 3-11).

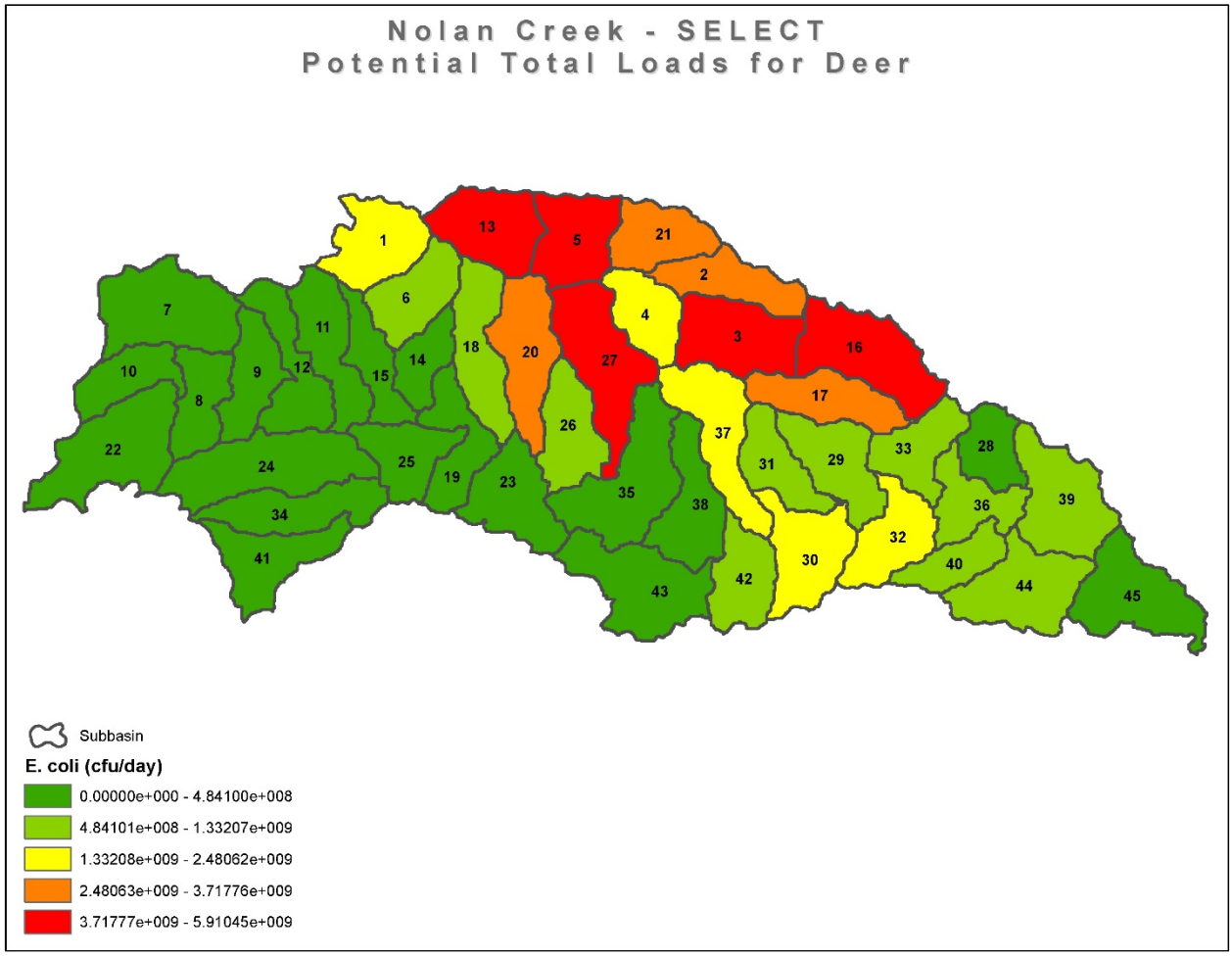

Figure 3-11 Distribution of potential *E. coli* loads from deer by subbasin within the Nolan Creek/South Nolan Creek watershed.

Pets

Domestic pets are another unregulated source of *E. coli* bacteria, particularly from dogs, because storm runoff often carries these wastes into streams (EPA, 2008). Bacteria sources that wash off the land from, particularly in developed areas, are often associated with pet wastes, primarily dogs. Other domestic animals, such as outdoor cats, also will contribute to potential loadings, but the number of cats is difficult to estimate as many are feral. In using SELECT, dogs are

generally considered a surrogate for pets in general. The American Veterinarian Medical Association (AVMA) estimates about 0.6 dogs per household throughout the U.S. and about 0.8 dogs per household in Texas (AVMA, 2012). Within the Nolan Creek/South Nolan Creek watershed, stakeholders estimated at least 1 dog per household and indicted the number likely may be larger. Loadings of *E. coli* from dogs was distributed based on the number of homes in each subwatershed using 2010 Census Block data (USCB, 2010; Figure 3-12).

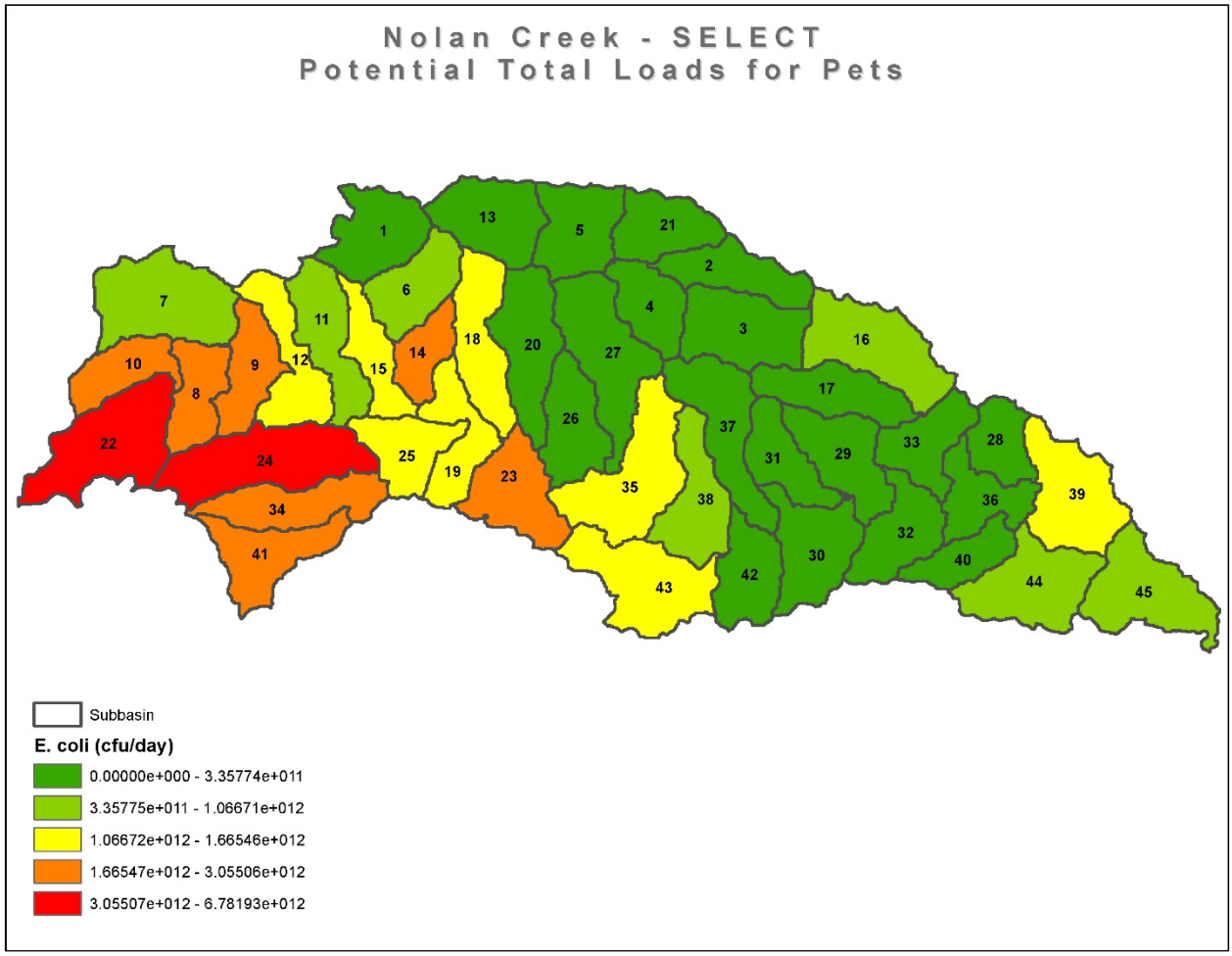

Figure 3-12 Distribution of potential *E. coli* loads from pets by subbasin within the Nolan Creek/South Nolan Creek watershed. Note: Pets are represented by an estimate of dog population density.

Of note, the estimation of loadings by dogs is in essence part of urban stormwater runoff for developed areas as it is based on housing density. Potential loadings from dogs were presented separately to allow the relative contribution of this source to be compared between subbasins. Also, the potential loadings from dogs will vary from the potential loadings associated with urban stormwater runoff as very different approaches were used in SELECT for these two types of sources.

On-Site Sewage Facilities

On-site sewage facilities (OSSFs) are often referred to as septic systems. These small waste management systems are generally associated with houses that are unable to connect to a central wastewater collection system. Septic systems are often used in rural areas, but may also exist in urban areas when subdivisions develop outside the area serviced by a centralized waste management system or when areas are annexed that have OSSFs that have not yet connected to a city's central waste management system. Within the Nolan Creek/South Nolan Creek watershed, the Bell County Health District deals with permitting of all new OSSFs. While there is a tracking of new systems through the permitting process, older or "grandfathered" systems (generally prior to 1989) are difficult to identify, because permits were not required for these. At this time, a complete inventory of OSSFs within the watershed does not exit and available information for most of the watershed is not in a format that can easily be mapped. Some data on locations of OSSFs was made available by the City of Killeen as part of its Septic Tank Elimination Program (STEP) and the location of these is shown in Figure 3-13.

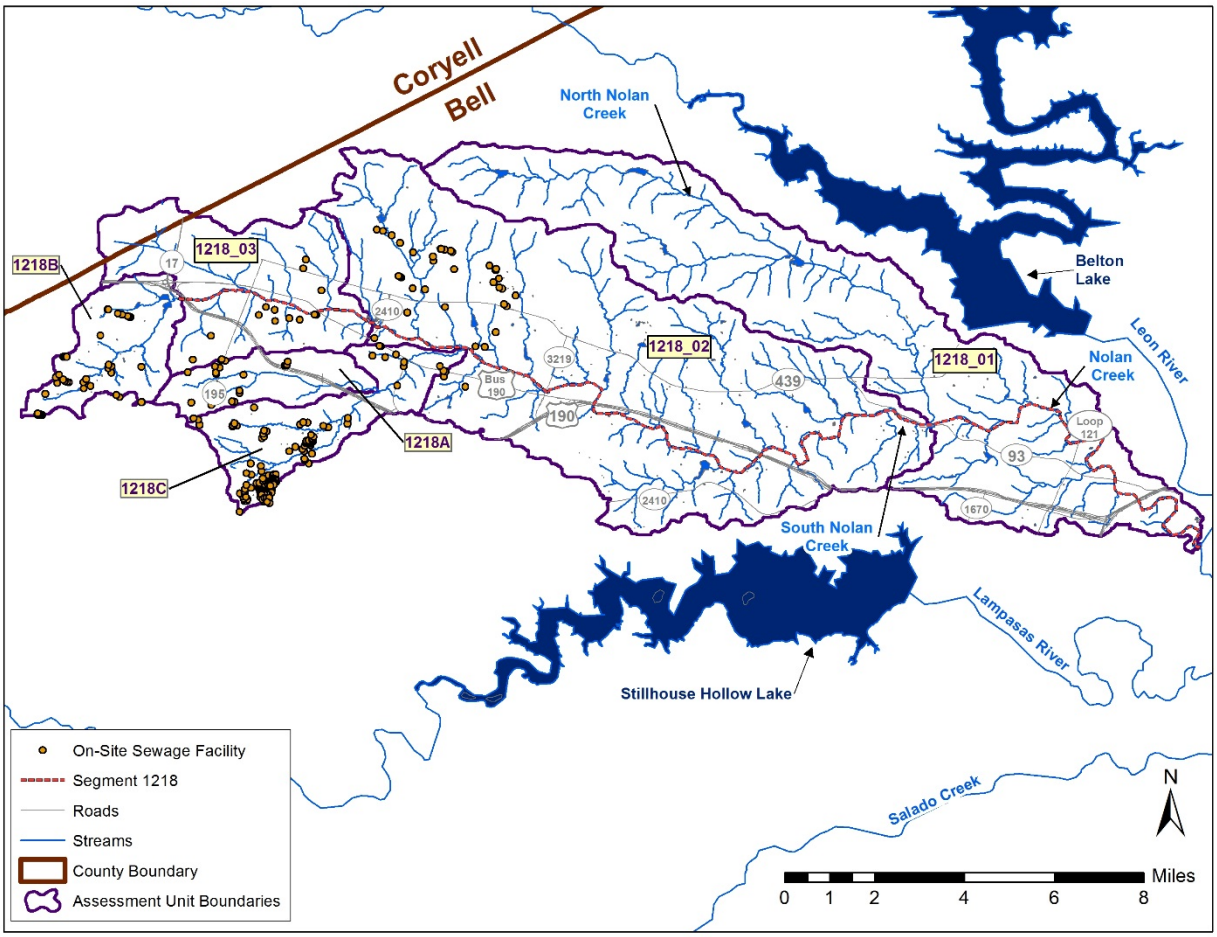

Figure 3-13 Location of OSSFs within City of Killeen municipal boundaries. Source: City of Killeen.

To account for potential *E. coli* loadings from septic systems with SELECT, the number of homes within each subwatershed not covered by public wastewater services were identified by masking out the area serviced by sewer systems in conjunction with 2010 Census Block data (USCB, 2010). Within the rural area, an estimated 2,180 households exist containing on average three people per household based the 2010 census block data (USCB, 2010). Information from the City of Killeen indicated an additional 273 households on OSSFs within its municipal boundaries (Figure 3-13). The estimated rural households in conjunction with the site-specific data provided by the City of Killeen were used in SELECT to estimate the density of OSSFs within each subwatershed.

Soils data from the Natural Resources Conservation Service (NRCS) were then obtained from the Soil Survey Geographic (SSURGO) database and used to calculate the potential failure rate of septic systems within a subwatershed based on the dominate limitation class associated with the septic tank absorption fields (USDA-NRCS, 2015). According to the Bell County Soil Survey, soils within the watershed fall into two major associations; the Denton-Purves and the Speck-Tarrant-Purves (Huckabee et al., 1977). The majority of the watershed draining to South Nolan Creek is part of the Denton-Purves soil association, while the watershed draining to North Nolan Creek and most of Nolan Creek is part of the Speck-Tarrant-Purves association. Both the Denton and Purves soil series are noted to have severe limitations for septic tank absorption fields based on shallow depth to bedrock (8 to 40 inches). The Denton series is noted for slow permeability. Severe limitations are noted for septic tanks absorption fields for the three major soil series in the Speck-Tarrant-Purves association due to shallow depth to bedrock (8 to 20 inches) for all three and slow permeability for the Speck soil series.

The failure rate within SELECT associated with limitation classes for septic drainage fields was as follows (Borel, et al., 2012; USDA-SCS, 1993):

- 15% for severely limited,
- 10% moderately limited,
- 5% for slightly limited, and
- 15% for not rated.

Within SELECT, the *E. coli* loading for each subwatershed is calculated as follows:

E. coli (cfu/day) = (# septic systems) * (average # people/household) * (*E. coli* production rate in cfu/100 mL) * (failure rate) * (individual usage in gallons/person) * (3758.2 mL/gallon)

For the Nolan Creek/South Nolan Creek watershed, SELECT was applied assuming an *E. coli* production rate of $5x10^6$ cfu/100 mL with a daily usage of 60 gallons per person per day. The highest relative loadings from OSSFs generally was associated with an area near Harker Heights and Nolanville and to the northwest of the City of Belton (Figure 3-14). A moderate loading was also associated with subbasin 41, within the City of Killeen, which is an area still containing a high density of households on OSSFs (see Figure 3-13).

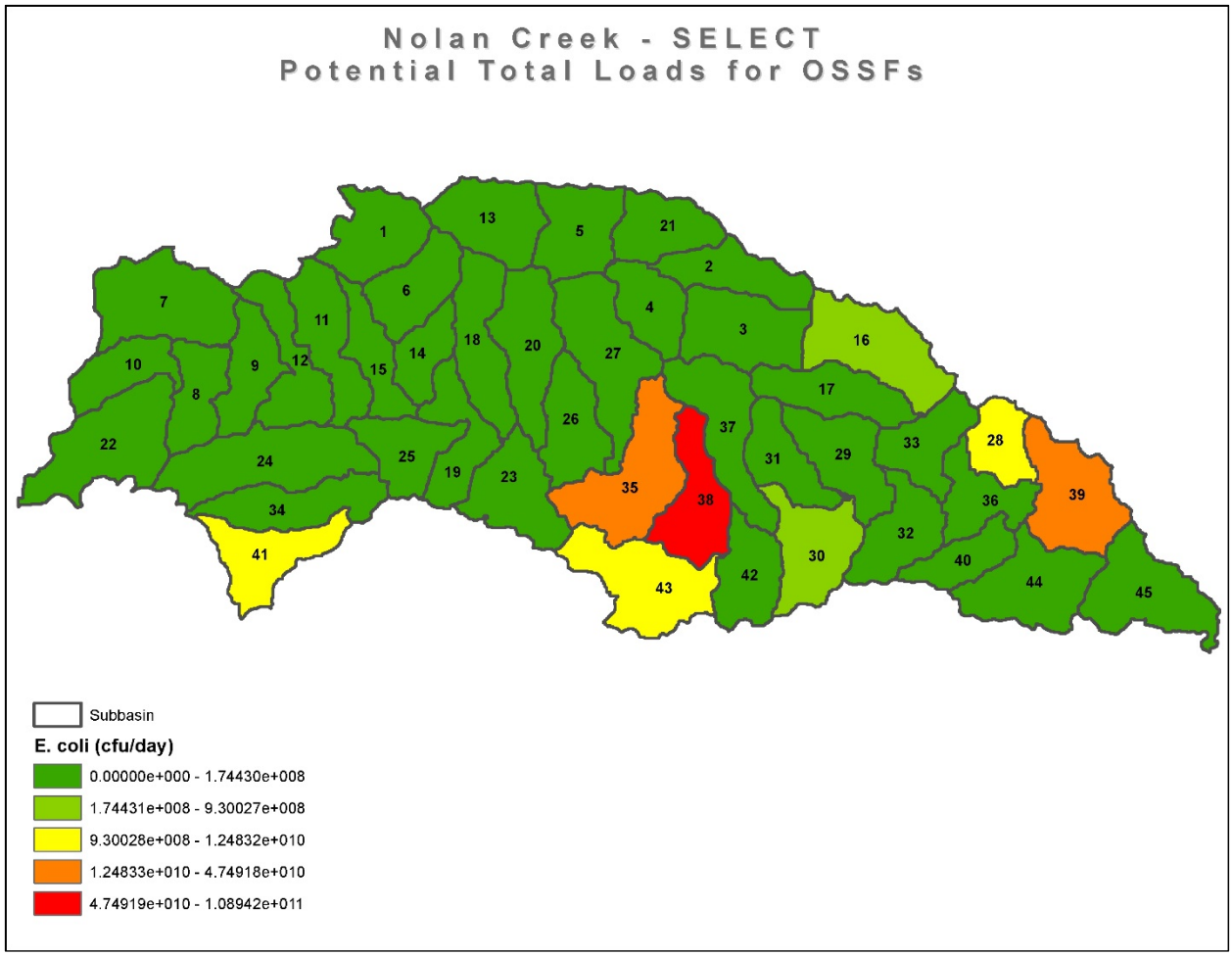

Figure 3-14 Distribution of potential *E. coli* loads from OSSFs by subbasin within the Nolan Creek/South Nolan Creek watershed.

Combined Sources

While the methods used for estimating various potential loadings from regulated and non-regulated sources differ, combining them presents an overall picture of potential "hot spots" within the watershed (Figure 3-15). Of note, even subbasins with low potential loadings (those in dark green in Figure 3-15) still may have loadings exceeding the criterion. For example, the lowest total potential loading was estimated in subbasin 5 as 2.85E+12 cfu/day. Under moderate flow conditions for the LDCs, allowable loads were 2.69E+11 cfu/day or less (see Figures 2-3 through 2-6).

Potential loading by source and subbasin are shown in a tabular format in Appendix B along with the percent comprised by each source within subbasin. This aids in identifying potential impairment sources by subbasin for bacteria that need to be controlled, an important element in watershed based planning (EPA, 2003). In the more western portion of the watershed, urban stormwater and pet waste appeared to be the dominant potential sources, while in the mid-portion of the watershed in the yellow-colored subbasins, cattle appeared as the dominant potential source.

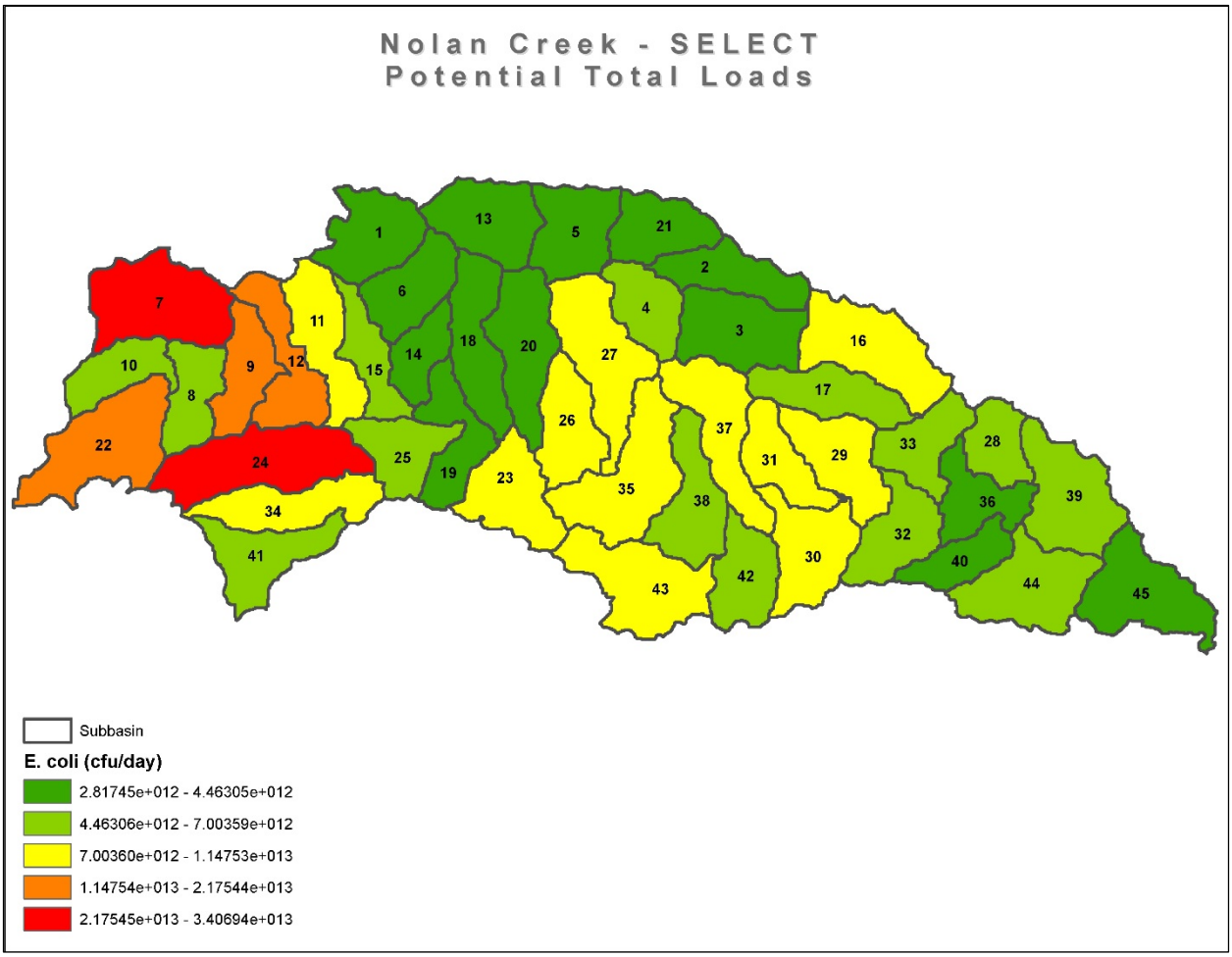

Figure 3-15 Distribution of potential *E. coli* loads from all SELECT sources by subbasin within the Nolan Creek/South Nolan Creek watershed.

SECTION 4

Summary and Discussion

Use of LDCs and SELECT help highlight flow conditions and potential sources of bacteria loadings in the Nolan Creek/South Nolan Creek watershed. The LDCs indicate that wet-weather events generally associated with nonpoint sources lead to the highest loadings during high and moderate flows, but that some excursions above criterion occur during low flow conditions indicating a need to control some dry weather contributions. The SELECT maps provide a spatial representation of the potential major sources, which for the Nolan Creek/South Nolan Creek watershed include urban stormwater and pets in the western portion of the watershed and cattle predominately in the mid-portion of the watershed. A focus then is to match up what these two tools tell us about actual and potential loadings in the watershed with what we know about instream water quality.

Of note, LDCs match assessment data in indicating bacteria concentrations below assessment levels during low and moderate flows at the most upstream station, 18828 (Figure 2-3). Some subbasins from SELECT above station 18828 (subbasins 7, 9, 12 and 22 within AUs 1218_03 and 1218B; see Figure 3-1) in contrast indicated some of the highest potential loadings, primarily from urban stormwater runoff (Figure 3-6). This is a case where potential loadings may already be adequately controlled in that water quality is already meeting target levels. The same appears to be apparent for SELECT subbasin 24, which represents assessment unit 1218A. Based on results presented in the TCEQ 2012 Texas Integrated Report, AU 1218A is in compliance for bacteria (TCEQ, 2013), even though some of the highest potential bacteria loadings are associated with this subbasin.

The areas of the watershed noted as impaired for bacteria are AU 1218C, Little Nolan Creek, and 1218_02, portions of South Nolan Creek (see Figure 1-1). Station 11913 is located on South Nolan Creek below the confluence with of Little Nolan Creek. The SELECT subbasins associated with the area between monitoring stations 18828 and 11913 not associated with Little Nolan Creek (subbasins 1, 6, 14, 15, 18, and 19) show potential loadings primarily from urban stormwater and pets, but also cattle (see Appendix B). Along Little Nolan Creek (subbasins 25, 34, and 41), urban stormwater and pets were the dominant potential sources, although OSSFs were also a minor but notable potential contributor.

Further along South Nolan Creek at station 11910, bacteria loads are generally higher compared to those at station 11913 using the LDC analysis (Figures 2-4 and 2-5). The SELECT subbasins do not break exactly between stations 11913 and 11910, but are mainly subbasins 18, 20, 23, 26, and 27. Of these five subbasins, cattle is the dominant potential source in subbasins 20, 26, and 27; urban stormwater is the dominant potential source in subbasin 23; and within subbasin 18, cattle and pets are dominant followed by urban stormwater as potential loading sources. While urban land is prominent in the watershed, it appears in the area between stations 11913 and 11910 a focus on both urban and agricultural sources is needed to target reduction efforts.

Moving further downstream to station 11905, loadings are still above target levels based on the LDCs for low and moderate flows, but much closer to compliance levels than those noted at

station 11913. Between stations 11910 and 11905, SELECT output indicates cattle as the dominant potential source. Other prominent sources in this area include urban stormwater with subbasin 35, but then pets, sheep/goats, and feral hogs in the more rural subbasins (29-32, 37, 38, and 43).

Overall, SELECT indicates a mix of urban and rural land uses contributing to the potential bacteria loading within the Nolan Creek/South Nolan Creek watershed. SELECT also shows that in relation to instream water quality data, some areas, such as above station 18828 the most upstream station monitored, that what is indicated as potential sources may not be a problem, at least not during baseflow conditions associated with most assessment monitoring. The SELECT methodology enables a pictorial presentation of the potential bacterial loadings from what are considered common sources within a watershed. It should be emphasized that SELECT does not depict all sources nor actual loadings. The purpose of applying SELECT, as well as LDCs, is to engage stakeholders in identifying sources within impaired waterbodies, and also to help them determine cost-effective restoration efforts to reduce bacteria loadings in the watershed, thus, preserving its use for primary contact recreation.

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Appendix A: Nutrient LDCs

Nutrient LDCs are shown for nitrate (Figures A-1 – A-4), ortho-P (Figures A-5 – A-8), and total-P (Figures A-9 – A-12). Nutrients were compared to screening levels of 1.95 mg/L nitrate, 0.37 mg/L ortho-P, and 0.69 mg/L total-P for calculating allowable loadings. The percent reductions estimated to meet screening levels are indicated in Table A-1 – A-3. Unlike bacteria, nutrients indicated lower reductions under higher flow regimes indicating primarily point source or dry weather loadings. Only at station 18828, the most upstream location monitored, were screening levels met, but then only under high flow conditions. Reductions in nutrient concentrations were 58 to 87 percent during moderate to low flow conditions and 0 to 56 percent during high flow conditions.

Of note, in developing the LDCs for nutrients, most of the wet-weather or high flow samples represented flow-weighted samples collected during storm events. The flow associated with these samples represented an average flow over the time period of sample collection. This average flow for each flow-weighted storm sample was calculated based on reported stage data and derived stage-discharge relationships for each storm monitoring station, which are presented in the monitoring data report for this project.

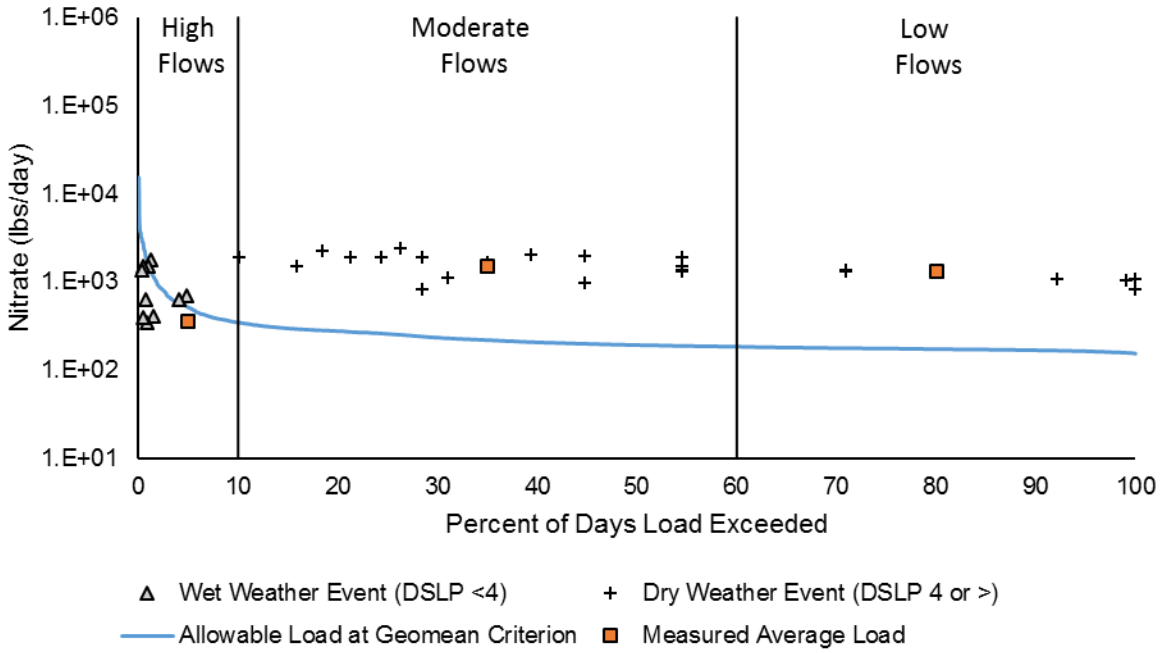

Figure A-1 Nitrate load duration curve for station 18828, South Nolan Creek at 38th Street

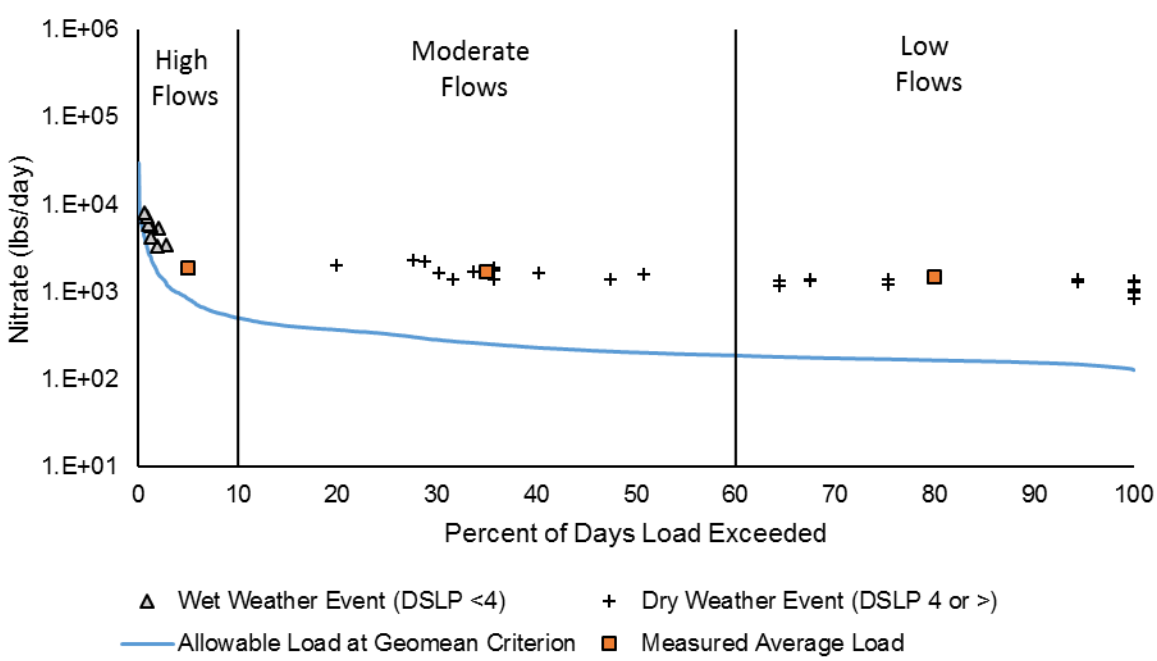

Figure A-2 Nitrate load duration curve for station 11913, South Nolan Creek at Roy Reynolds Road.

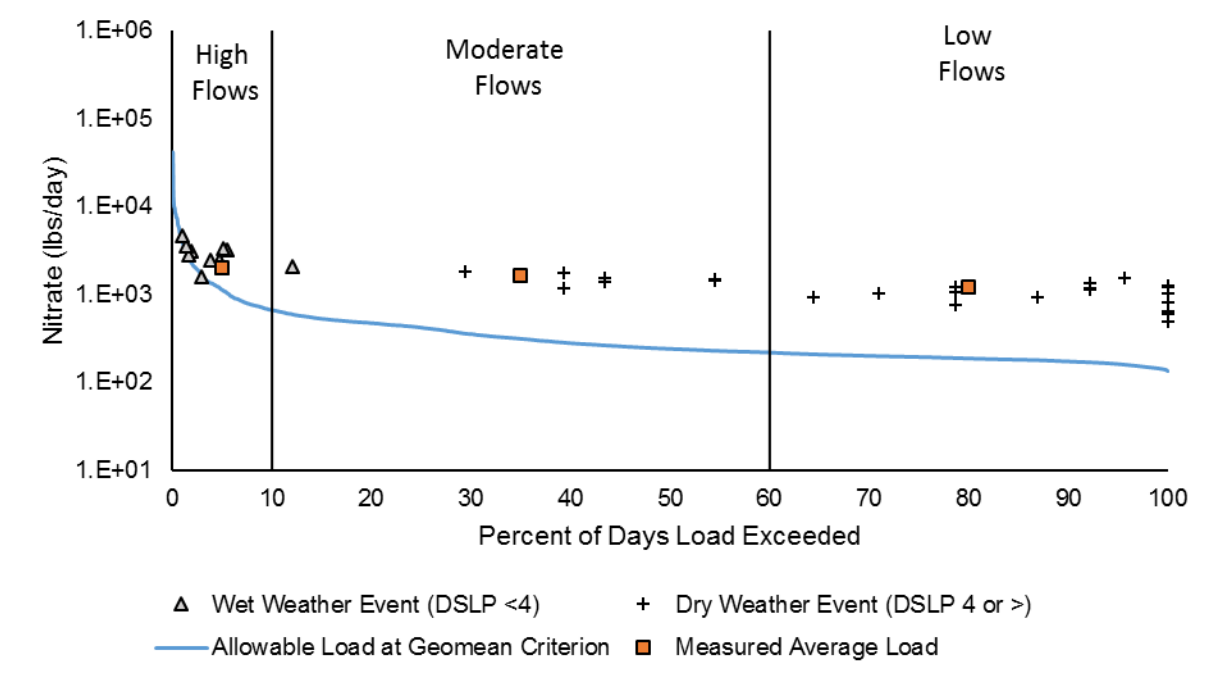

Figure A-3 Nitrate load duration curve for station 11910, Nolan Creek at US 190.

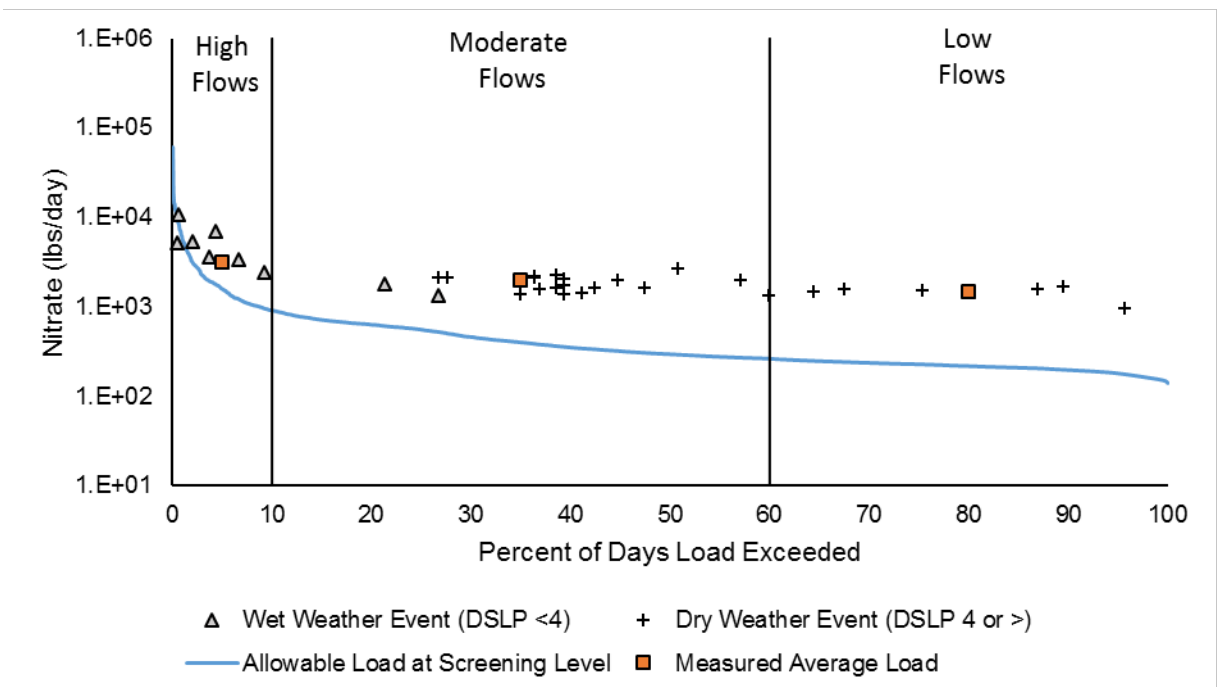

Figure A-4 Nitrate load duration curve for station 11905, Nolan Creek at Backstrom Crossing.

Table A-1 Average concentration of measured nitrate by flow regime and estimated percent reductions needed to meet screening level of 1.95 mg/L nitrate for four stations along Nolan Creek/South Nolan Creek. Negative percent reductions indicate the screening level is already met and reductions are not necessary.

Station	High Flows (0-10%)		Moderate Flows (10-60%)		Low Flows 60-100%)	
	Average Nitrate (m/g/L)	Percent Reduction	Average Nitrate (m/g/L)	Percent Reduction	Average Nitrate (m/g/L)	Percent Reduction
18828	1.31	-49%	13.5	86%	14.7	87%
11913	4.46	56%	13.0	85%	13.0	85%
11910	3.41	43%	10.4	81%	12.7	85%
11905	4.08	52%	9.65	80%	13.1	85%

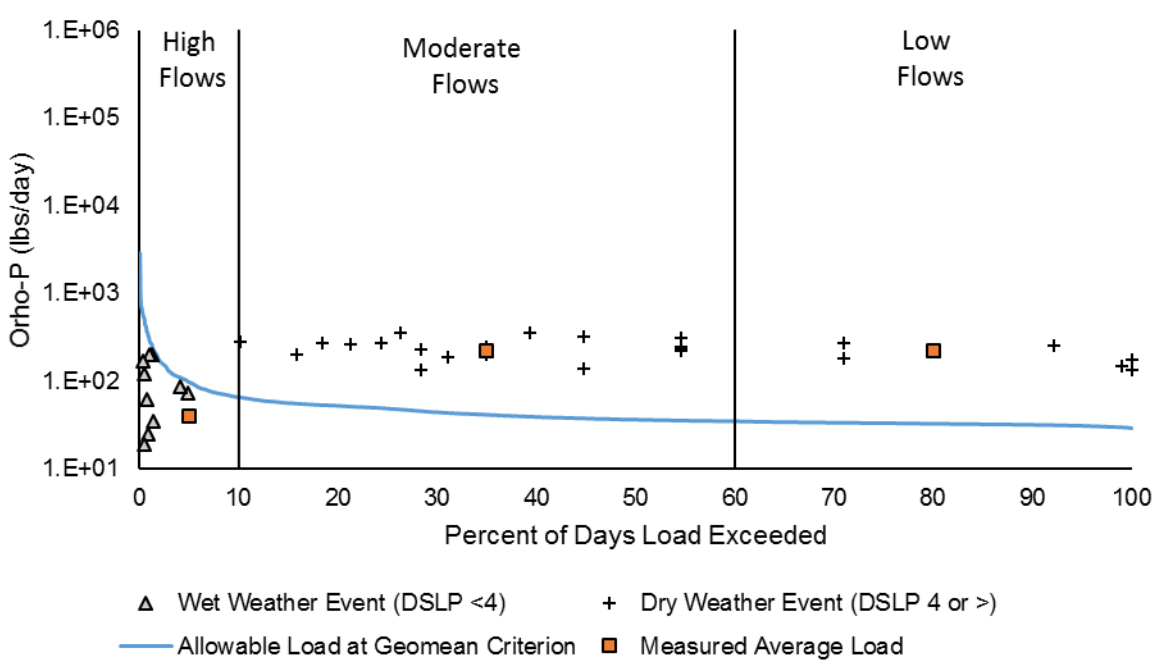

Figure A-5 Ortho-P load duration curve for station 18828, South Nolan Creek at 38th Street

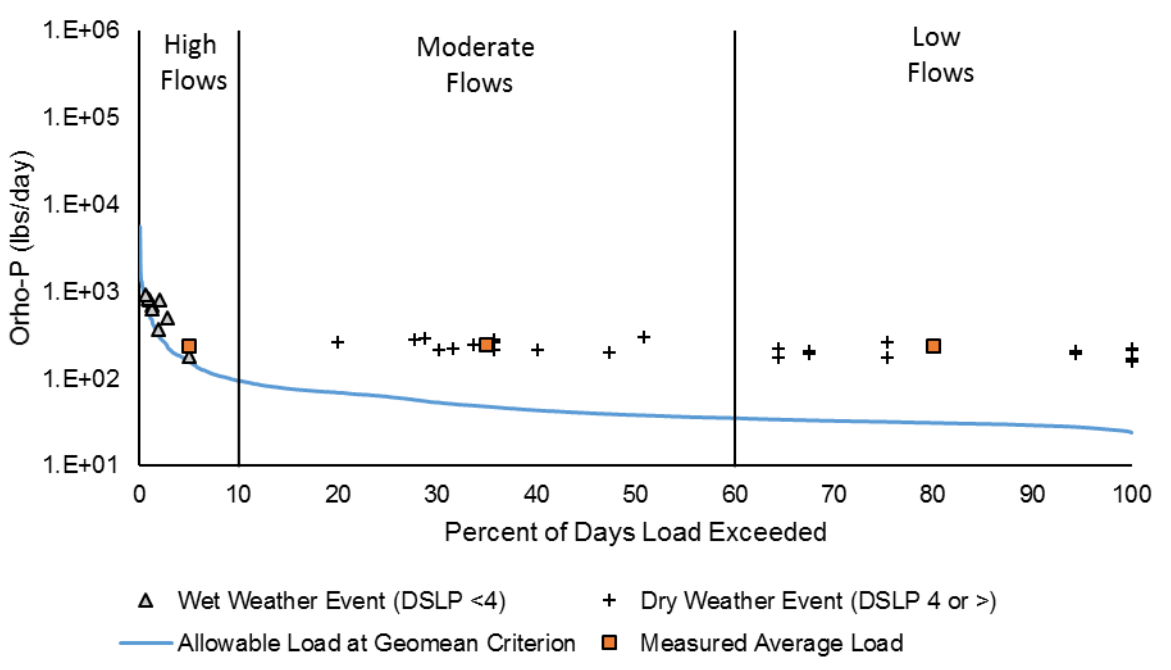

Figure A-6 Ortho-P load duration curve for station 11913, South Nolan Creek at Roy Reynolds Road.

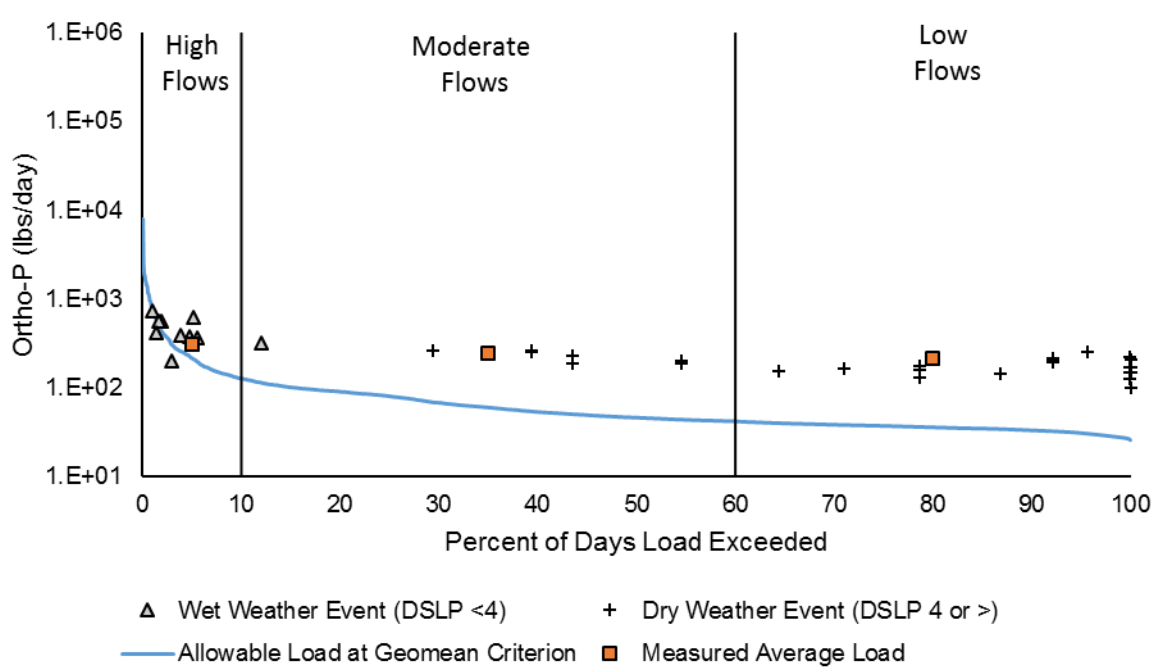

Figure A-7 Ortho-P load duration curve for station 11910, Nolan Creek at US 190.

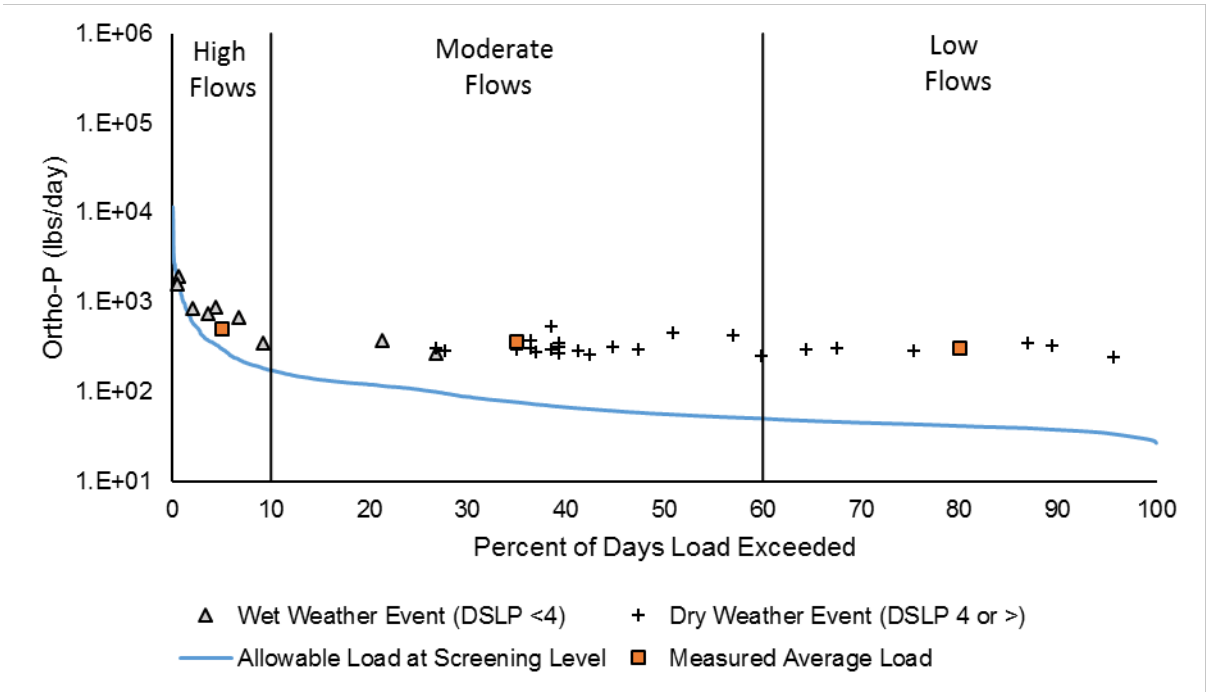

Figure A-8 Ortho-P load duration curve for station 11905, Nolan Creek at Backstrom Crossing.

Table A-2 Average concentration of measured ortho-P by flow regime and estimated percent reductions needed to meet screening level of 0.37 mg/L ortho-P for four stations along Nolan Creek/South Nolan Creek. Negative percent reductions indicate the screening level is already met and reductions are not necessary.

Station	High Flows (0-10%)		Moderate Flows (10-60%)		Low Flows 60-100%)	
	Average Ortho-P (m/g/L)	Percent Reduction	Average Ortho-P (m/g/L)	Percent Reduction	Average Ortho-P (m/g/L)	Percent Reduction
18828	0.15	-155%	1.99	81%	2.51	85%
11913	0.57	36%	1.89	80%	2.73	86%
11910	0.52	28%	1.55	76%	2.22	83%
11905	0.65	43%	1.74	79%	2.71	86%

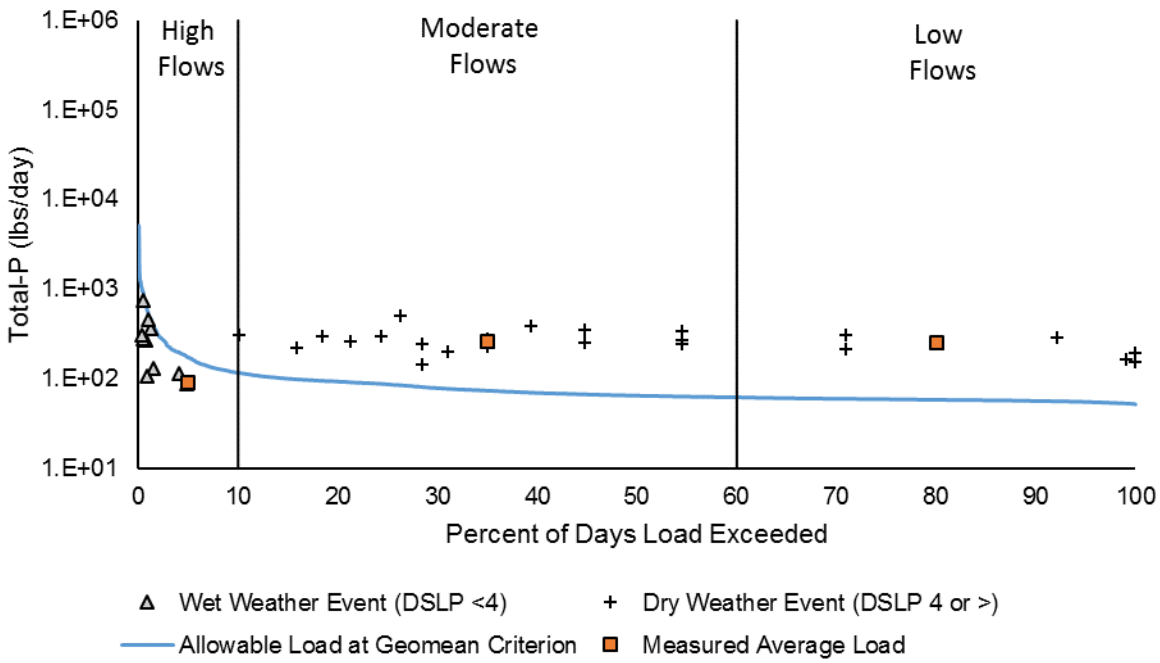

Figure A-9 Total-P load duration curve for station 18828, South Nolan Creek at 38th Street

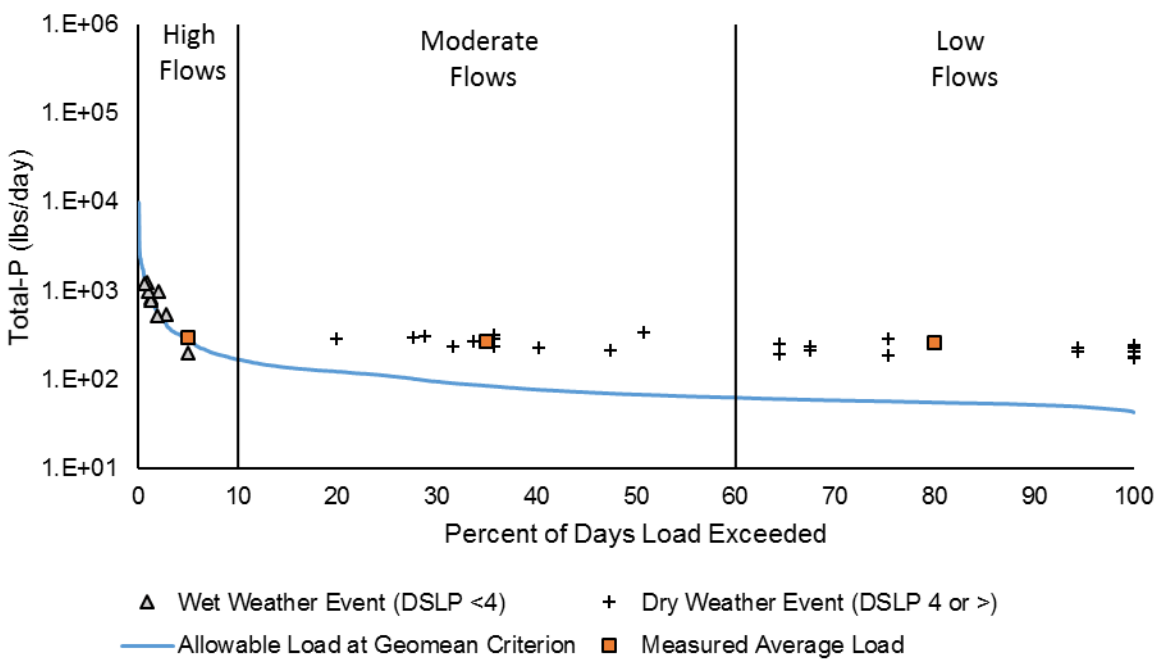

Figure A-10 Total-P load duration curve for station 11913, South Nolan Creek at Roy Reynolds Road.

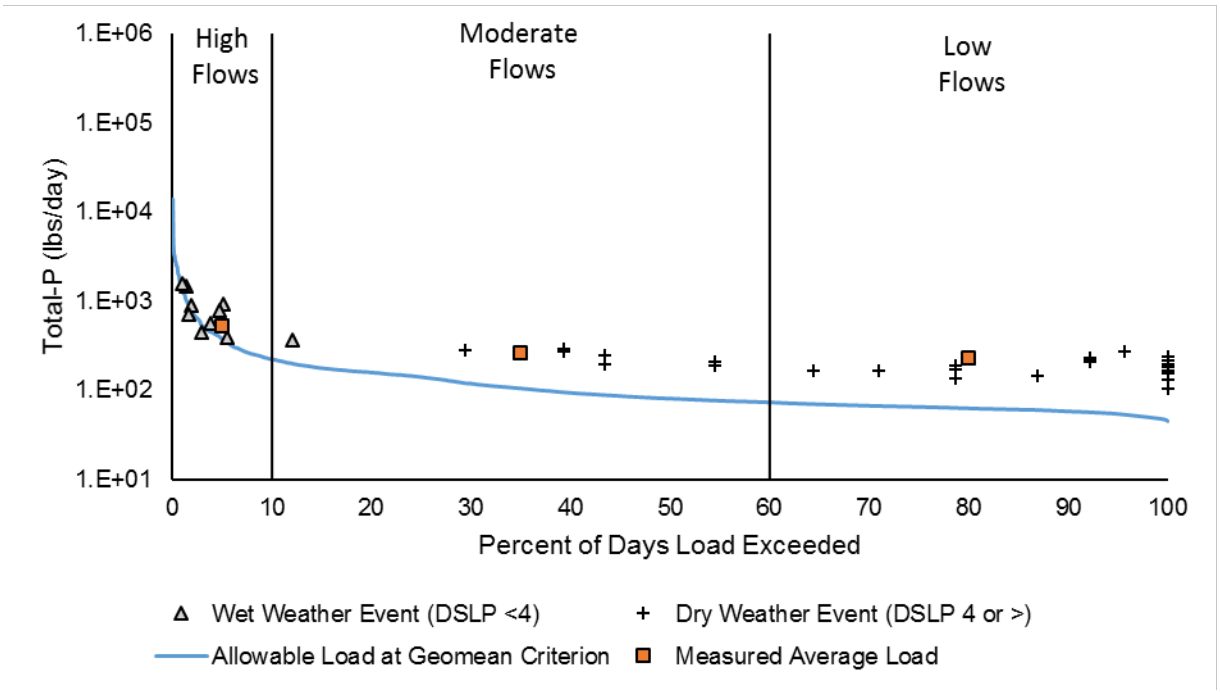

Figure A-11 Total-P load duration curve for station 11910, Nolan Creek at US 190.

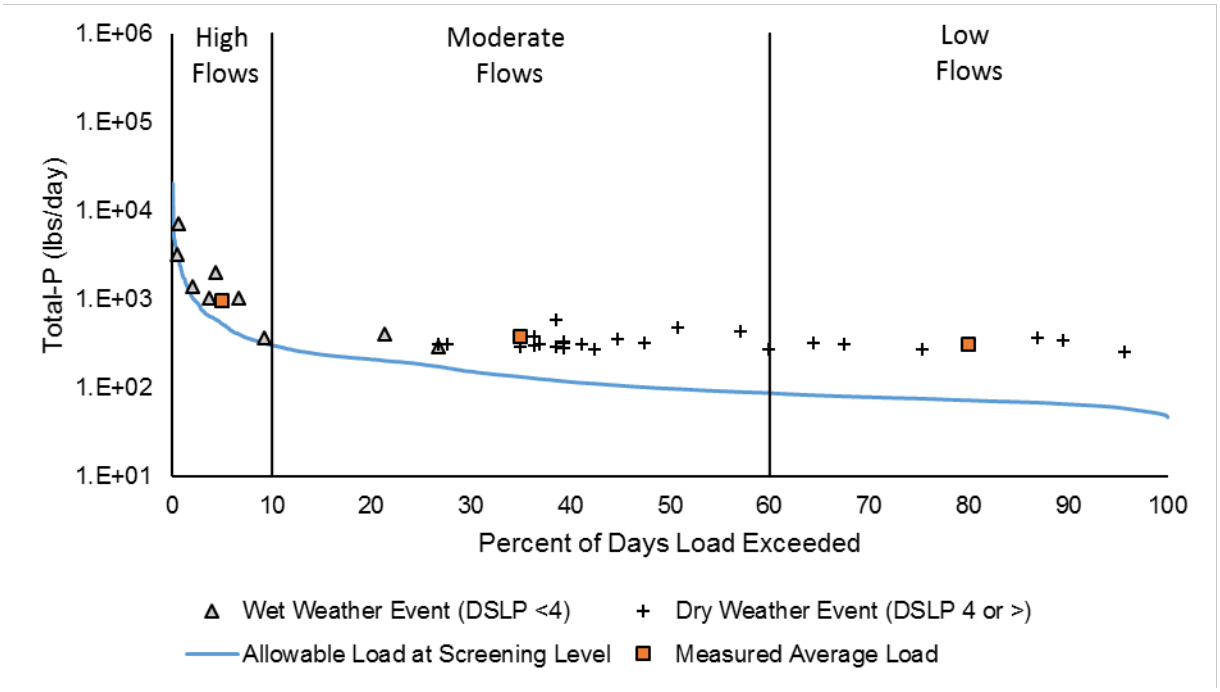

Figure A-12 Total-P load duration curve for station 11905, Nolan Creek at Backstrom Crossing.

Table A-3 Average concentration of measured total-P by flow regime and estimated percent reductions needed to meet screening level of 0.69 mg/L total-P for four stations along Nolan Creek/South Nolan Creek. Negative percent reductions indicate the screening level is already met and reductions are not necessary.

Station	High Flows (0-10%)		Moderate Flows (10-60%)		Low Flows 60-100%)	
	Average Total-P (m/g/L)	Percent Reduction	Average Total-P (m/g/L)	Percent Reduction	Average Total-P (m/g/L)	Percent Reduction
18828	0.33	-107%	2.28	70%	2.78	75%
11913	0.71	3%	2.03	66%	2.99	77%
11910	0.88	22%	1.65	58%	2.38	71%
11905	1.25	45%	1.84	62%	2.83	76%

Appendix B: SELECT Estimates of Potential Loadings by Subbasin and Source

Table B-1 SELECT estimates of potential loadings by subbasin and source for Nolan Creek/South Nolan Creek.

Subbasin	Cattle (cfu/day)	Sheep & Goats (cfu/day)	Horses (cfu/day)	Deer (cfu/day	Feral Hogs (cfu/day)	Pets (cfu/day)	OSSFs (cfu/day)	WWTF (cfu/day)	Urban Stormwater (cfu/day)	Total (cfu/day)
1	2.13E+12	2.28E+11	9.55E+08	1.98E+09	1.11E+11	0.00E+00	0.00E+00	0.00E+00	3.78E+11	2.85E+12
2	2.59E+12	3.83E+11	1.16E+09	3.72E+09	2.67E+11	0.00E+00	0.00E+00	0.00E+00	3.64E+03	3.25E+12
3	2.65E+12	5.53E+11	1.19E+09	5.91E+09	4.46E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.65E+12
4	4.23E+12	3.41E+11	1.90E+09	2.48E+09	2.41E+11	0.00E+00	0.00E+00	0.00E+00	7.23E+05	4.81E+12
5	2.07E+12	4.62E+11	9.28E+08	5.00E+09	2.84E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.82E+12
6	1.82E+12	1.64E+11	8.17E+08	1.26E+09	1.31E+11	1.07E+12	1.99E+00	0.00E+00	1.10E+12	4.28E+12
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.08E+11	0.00E+00	0.00E+00	2.65E+13	2.70E+13
8	0.00E+00	1.38E+09	0.00E+00	2.21E+07	0.00E+00	2.01E+12	6.08E-08	0.00E+00	4.08E+12	6.09E+12
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.22E+12	6.08E-08	0.00E+00	1.22E+13	1.44E+13
10	4.84E+11	4.71E+10	2.17E+08	3.89E+08	5.48E+10	2.16E+12	1.98E+00	4.29E+08	2.12E+12	4.87E+12
11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.55E+11	9.11E-08	0.00E+00	1.05E+13	1.15E+13
12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.37E+12	2.21E-04	0.00E+00	1.56E+13	1.70E+13
13	2.37E+12	4.89E+11	1.06E+09	5.21E+09	2.82E+11	0.00E+00	0.00E+00	0.00E+00	4.17E+06	3.15E+12
14	7.33E+09	2.64E+08	3.29E+06	0.00E+00	0.00E+00	2.54E+12	2.65E-04	0.00E+00	1.92E+12	4.46E+12
15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+12	0.00E+00	1.14E+11	5.57E+12	7.00E+12
16	5.49E+12	5.88E+11	2.47E+09	5.06E+09	4.11E+11	8.62E+11	9.30E+08	1.43E+08	2.47E+09	7.36E+12
17	5.15E+12	4.36E+11	2.31E+09	3.20E+09	3.12E+11	8.34E+10	1.84E+04	0.00E+00	8.25E+05	5.98E+12
18	1.46E+12	1.48E+11	6.55E+08	1.20E+09	9.37E+10	1.42E+12	1.15E+01	0.00E+00	6.58E+11	3.78E+12
19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.67E+12	1.10E-04	0.00E+00	2.70E+12	4.37E+12
20	3.08E+12	3.61E+11	1.38E+09	3.19E+09	1.65E+11	1.91E+11	3.23E+04	0.00E+00	7.77E+09	3.81E+12
21	2.67E+12	3.72E+11	1.20E+09	3.57E+09	2.61E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.31E+12
22	1.25E+11	6.66E+09	5.60E+07	3.16E+07	0.00E+00	6.78E+12	3.58E+04	0.00E+00	1.48E+13	2.18E+13
23	1.06E+11	6.00E+09	4.78E+07	2.53E+07	0.00E+00	2.31E+12	5.80E-04	1.43E+10	6.78E+12	9.21E+12

Subbasin	Cattle (cfu/day)	Sheep & Goats (cfu/day)	Horses (cfu/day)	Deer (cfu/day	Feral Hogs (cfu/day)	Pets (cfu/day)	OSSFs (cfu/day)	WWTF (cfu/day)	Urban Stormwater (cfu/day)	Total (cfu/day)
24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.73E+12	5.82E+01	0.00E+00	2.83E+13	3.41E+13
25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+12	2.98E+00	0.00E+00	3.91E+12	5.29E+12
26	6.84E+12	3.00E+11	3.07E+09	6.87E+08	1.68E+11	3.36E+11	3.31E+07	0.00E+00	8.07E+10	7.73E+12
27	6.20E+12	6.24E+11	2.79E+09	5.16E+09	4.08E+11	1.49E+11	1.13E+05	0.00E+00	1.49E+09	7.39E+12
28	4.92E+12	2.11E+11	2.21E+09	4.43E+08	1.67E+11	3.02E+11	1.25E+10	0.00E+00	3.73E+09	5.62E+12
29	9.06E+12	4.27E+11	4.07E+09	1.33E+09	3.60E+11	1.15E+11	1.99E+06	0.00E+00	1.96E+09	9.97E+12
30	7.46E+12	4.18E+11	3.35E+09	1.91E+09	3.32E+11	7.57E+10	5.55E+08	0.00E+00	9.70E+09	8.30E+12
31	7.36E+12	3.27E+11	3.31E+09	7.91E+08	2.42E+11	9.83E+10	2.51E+04	0.00E+00	1.50E+09	8.03E+12
32	5.14E+12	3.39E+11	2.31E+09	1.97E+09	2.40E+11	6.80E+10	1.60E+04	0.00E+00	9.23E+08	5.80E+12
33	5.80E+12	2.59E+11	2.60E+09	6.55E+08	2.36E+11	2.35E+11	1.41E+07	0.00E+00	9.03E+09	6.54E+12
34	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.06E+12	4.54E+03	0.00E+00	6.43E+12	9.48E+12
35	4.63E+12	1.96E+11	2.08E+09	3.51E+08	1.71E+11	1.67E+12	4.75E+10	2.86E+10	8.93E+11	7.63E+12
36	3.67E+12	2.15E+11	1.65E+09	1.06E+09	2.63E+11	9.73E+10	2.87E+04	0.00E+00	1.61E+08	4.25E+12
37	8.42E+12	4.40E+11	3.78E+09	1.81E+09	3.81E+11	2.81E+11	6.01E+04	0.00E+00	8.72E+09	9.54E+12
38	4.71E+12	2.07E+11	2.12E+09	4.84E+08	1.74E+11	6.93E+11	1.09E+11	3.22E+09	3.81E+11	6.28E+12
39	4.35E+12	2.30E+11	1.95E+09	9.43E+08	2.27E+11	1.32E+12	3.09E+10	0.00E+00	8.15E+10	6.25E+12
40	2.42E+12	1.75E+11	1.09E+09	1.14E+09	1.45E+11	1.61E+11	2.37E+07	0.00E+00	2.88E+10	2.93E+12
41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.02E+12	5.07E+09	0.00E+00	3.17E+12	5.20E+12
42	4.18E+12	2.49E+11	1.88E+09	1.24E+09	2.26E+11	1.32E+11	6.35E+06	0.00E+00	2.51E+10	4.82E+12
43	5.10E+12	1.99E+11	2.29E+09	2.02E+08	1.89E+11	1.59E+12	7.51E+09	0.00E+00	9.93E+10	7.18E+12
44	3.90E+12	2.19E+11	1.75E+09	1.00E+09	1.22E+11	6.72E+11	1.74E+08	0.00E+00	2.00E+11	5.11E+12
45	3.12E+11	2.05E+10	1.40E+08	1.20E+08	2.49E+10	9.25E+11	2.02E+02	4.77E+10	2.75E+12	4.08E+12

Table B-2 Percent of potential loadings by source within subbasins for Nolan Creek/South Nolan Creek.

Subbasin	Cattle	Sheep & Goats	Horses	Deer	Feral Hogs	Pets	OSSFs	WWTF	Urban Stormwater
1	74.72%	7.99%	0.03%	0.07%	3.90%	0.00%	0.00%	0.00%	13.28%
2	79.82%	11.81%	0.04%	0.11%	8.21%	0.00%	0.00%	0.00%	0.00%
3	72.44%	15.14%	0.03%	0.16%	12.22%	0.00%	0.00%	0.00%	0.00%
4	87.81%	7.09%	0.04%	0.05%	5.01%	0.00%	0.00%	0.00%	0.00%
5	73.33%	16.38%	0.03%	0.18%	10.07%	0.00%	0.00%	0.00%	0.00%
6	42.48%	3.83%	0.02%	0.03%	3.05%	24.92%	0.00%	0.00%	25.67%
7	0.00%	0.00%	0.00%	0.00%	0.00%	1.88%	0.00%	0.00%	98.12%
8	0.00%	0.02%	0.00%	0.00%	0.00%	32.97%	0.00%	0.00%	67.00%
9	0.00%	0.00%	0.00%	0.00%	0.00%	15.38%	0.00%	0.00%	84.62%
10	9.94%	0.97%	0.00%	0.01%	1.13%	44.37%	0.00%	0.01%	43.57%
11	0.00%	0.00%	0.00%	0.00%	0.00%	8.32%	0.00%	0.00%	91.68%
12	0.00%	0.00%	0.00%	0.00%	0.00%	8.09%	0.00%	0.00%	91.91%
13	75.30%	15.55%	0.03%	0.17%	8.95%	0.00%	0.00%	0.00%	0.00%
14	0.16%	0.01%	0.00%	0.00%	0.00%	56.86%	0.00%	0.00%	42.97%
15	0.00%	0.00%	0.00%	0.00%	0.00%	18.89%	0.00%	1.63%	79.48%
16	74.58%	7.98%	0.03%	0.07%	5.59%	11.70%	0.01%	0.00%	0.03%
17	86.02%	7.28%	0.04%	0.05%	5.21%	1.39%	0.00%	0.00%	0.00%
18	38.60%	3.92%	0.02%	0.03%	2.48%	37.51%	0.00%	0.00%	17.43%
19	0.00%	0.00%	0.00%	0.00%	0.00%	38.14%	0.00%	0.00%	61.86%
20	80.82%	9.49%	0.04%	0.08%	4.34%	5.02%	0.00%	0.00%	0.20%
21	80.75%	11.23%	0.04%	0.11%	7.87%	0.00%	0.00%	0.00%	0.00%
22	0.57%	0.03%	0.00%	0.00%	0.00%	31.17%	0.00%	0.00%	68.22%
23	1.15%	0.07%	0.00%	0.00%	0.00%	25.05%	0.00%	0.16%	73.58%
24	0.00%	0.00%	0.00%	0.00%	0.00%	16.83%	0.00%	0.00%	83.17%
25	0.00%	0.00%	0.00%	0.00%	0.00%	26.10%	0.00%	0.00%	73.90%

Subbasin	Cattle	Sheep & Goats	Horses	Deer	Feral Hogs	Pets	OSSFs	WWTF	Urban Stormwater
26	88.52%	3.87%	0.04%	0.01%	2.17%	4.34%	0.00%	0.00%	1.04%
27	83.90%	8.45%	0.04%	0.07%	5.51%	2.02%	0.00%	0.00%	0.02%
28	87.57%	3.76%	0.04%	0.01%	2.97%	5.37%	0.22%	0.00%	0.07%
29	90.89%	4.28%	0.04%	0.01%	3.61%	1.15%	0.00%	0.00%	0.02%
30	89.86%	5.04%	0.04%	0.02%	4.00%	0.91%	0.01%	0.00%	0.12%
31	91.63%	4.07%	0.04%	0.01%	3.01%	1.22%	0.00%	0.00%	0.02%
32	88.75%	5.84%	0.04%	0.03%	4.15%	1.17%	0.00%	0.00%	0.02%
33	88.66%	3.95%	0.04%	0.01%	3.61%	3.59%	0.00%	0.00%	0.14%
34	0.00%	0.00%	0.00%	0.00%	0.00%	32.22%	0.00%	0.00%	67.78%
35	60.65%	2.57%	0.03%	0.00%	2.24%	21.82%	0.62%	0.37%	11.70%
36	86.40%	5.06%	0.04%	0.02%	6.18%	2.29%	0.00%	0.00%	0.00%
37	88.29%	4.62%	0.04%	0.02%	3.99%	2.95%	0.00%	0.00%	0.09%
38	75.01%	3.30%	0.03%	0.01%	2.77%	11.03%	1.73%	0.05%	6.06%
39	69.65%	3.68%	0.03%	0.02%	3.63%	21.18%	0.49%	0.00%	1.31%
40	82.53%	5.97%	0.04%	0.04%	4.94%	5.50%	0.00%	0.00%	0.98%
41	0.00%	0.00%	0.00%	0.00%	0.00%	38.84%	0.10%	0.00%	61.07%
42	86.81%	5.17%	0.04%	0.03%	4.69%	2.75%	0.00%	0.00%	0.52%
43	70.95%	2.77%	0.03%	0.00%	2.64%	22.13%	0.10%	0.00%	1.38%
44	76.22%	4.29%	0.03%	0.02%	2.39%	13.14%	0.00%	0.00%	3.91%
45	7.63%	0.50%	0.00%	0.00%	0.61%	22.65%	0.00%	1.17%	67.44%